EXPERIMENTAL PSYCHOLOGY

MARY COLLINS

and

JAMES DREVER

প্রতিমা

A textbook for students attending a university or training college course in Experimental Psychology, and an introduction to this important aspect of Psychology for the general reader. The authors have also published separately a Laboratory Guide in Psychology for the college or university student: but the present book is complete in itself and describes in considerable detail typical experiments in psychology. A short description of the most important facts of Anatomy and Physiology, and references for additional reading are appended.

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EXPERIMENTAL PSYCHOLOGY

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WITH 27 DIAGRAMS

METHUEN & CO. LTD.
36 ESSEX STREET W.C.
LONDON

First published, February 1926
Reprinted nine times
Reprinted, 1952

9.2

CATALOGUE NO. 3245/U

PRINTED IN GREAT BRITAIN

PREFACE

THE present work was originally undertaken by Dr. Mary Collins with the intention of giving a popular presentation of the methods and results of Experimental Psychology. When the work was at a fairly advanced stage it became apparent that a much more useful book could be produced by somewhat extending its scope, without losing sight of the general reader, so as to cover the ground that a student might be reasonably expected to cover in a first year's university course in Experimental Psychology. Dr. Drever offering to collaborate, a thorough revision of the work was undertaken from the beginning, and its scope extended from this point of view. Some modifications were also introduced in the original plan. It was intended to append to each chapter a list of illustrative experiments which the reader could easily perform for himself, practically no apparatus being required. In the new plan these experiments have been dropped. A number of experiments are described in the text, but the authors hope shortly to publish a laboratory guide in Experimental Psychology, which will include such experimental work as a first year's student might be asked to carry out in the psychological laboratory. Moreover a summary account of the sense organs and the nervous system was added in an appendix in order to make the book more suitable as a text-book for first-year classes in Psychology.

A recent writer has stated that the systematic presentation of the science of Psychology is almost wholly divorced from the experimental work of the psychological laboratory. The authors would venture to suggest that the science has now reached such a stage of development that it can be taught from a point of view which is definitely experimental. The present book represents an attempt in this

direction. It is professedly elementary, but both with respect to omission and with respect to selection of topics the aim of introducing the student to General Psychology by the experimental pathway is kept in view throughout. It should also be noted that the book is intended as an introduction to, not a substitute for, such text-books of Experimental Psychology as those of Myers and Titchener.

The authors desire to place on record their indebtedness to Mr. L. Inglis Collins for the drawings for most of the figures in the text. They would also thank Messrs. Longmans for permission to reproduce from Lickley's *The Nervous System* the following figures in the Appendix: 18, 19, 23, 24 (from Gray's *Anatomy*) and 17 (from Quain's *Anatomy*).

M. C.
J. D

UNIVERSITY OF EDINBURGH
January, 1926

PREFATORY NOTE TO THIRD EDITION

SINCE the publication of this book the laboratory guide alluded to in the original Preface has appeared under the title: "A First Laboratory Guide in Psychology". The present edition has not been altered in any essential respect. Several corrections have been made, and a few foot-notes added.

M. C.
J. D.

UNIVERSITY OF EDINBURGH
November, 1929

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AN INTRODUCTION TO EXPERIMENTAL PSYCHOLOGY

INTRODUCTION

The Evolution of Experimental Psychology.—Psychology was one of the last of the sciences to develop the experimental method, at least systematically and on an extensive scale. The first psychological laboratory was established by Wundt at Leipzig as late as 1879. Naturally this does not represent the absolute beginning of the experimental development, but it does represent the earliest recognition of this development as being sufficiently important, and sufficiently extensive in scope, to demand the provision of special laboratory facilities, with special methods and special apparatus.

The laboratory psychology, originating with Wundt's laboratory, and for many years known as the "new" psychology, may be said to have taken its rise from different sources. The real impetus was derived from Locke and his followers, particularly perhaps those of the associationist school. One of the first results was the development of a physiological psychology, with which the beginnings of a true experimental psychology are so closely intertwined that it is difficult to disentangle the two from one another. That they are two quite separate lines of scientific progress must nevertheless be clearly recognized. The methods of the psychological laboratory are not the methods of physiology, and many of the problems studied in the psychological laboratory are not problems touching physiology at all, whereas physiological psychology is little more than an extension of physiology itself, both in respect of methods and in respect of problems.

These two lines of work may be said to have begun to diverge with the work of Fechner (1801-1887), in so far as that concerned

itself with mental measurement and the development of the so-called psycho-physical methods. This part of Fechner's work was founded on the generalization known as "Weber's Law," a generalization reached by Ernst Heinrich Weber (1795-1878), the anatomist and physiologist, on the basis of certain experiments on the estimation of lifted weights. The words in which he expressed the generalization were these: "in observando discrimine rerum inter se comparatarum non differentiam rerum, sed rationem differentiae ad magnitudinem rerum inter se comparatarum percipimus." That is to say, our estimation of a difference depends not on the absolute magnitude of the difference, but on the ratio of this to the magnitude of the things compared. On this generalization, which has since been found to hold within limits in other fields of sensory experience also, Fechner founded his whole system of mental measurement. He first of all obtained a mathematical expression for Weber's Law, which took the form: $I = k \log R$, where I = the intensity of a sensation, and R = the stimulus intensity, k being a constant determinable for the different senses and for different individuals.

Fechner's mathematical formula led to a great deal of controversy with which we need not concern ourselves here. The practical outcome was the systematic study of sensation by laboratory methods, which became characteristic of this department of experimental psychology, designated by Fechner "Psychophysics." However shaky may be the theoretical foundations of "Fechner's Law" and of his psycho-physical methods, of which we shall speak presently, the actual development of a new branch of experimental science was a concrete fact which no criticism could shake. Beginning thus with sensation, experimental methods were soon extended to other fields of psychological enquiry—attention, memory, thought, feeling—and the development proceeded with great rapidity after psychological laboratories on the model of Wundt's began to be established in other university centres, particularly in Germany and in America.

It ought to be noted that a movement, to a large extent independent of this development, was taking place in England under the influence of Francis Galton. This movement later coalesced with the German movement in the Experimental Psychology of the present day. Galton's work on the psychological side was in the main qualitative rather than quantitative, and his methods never reached the elaboration of those

of Fechner. Nevertheless he must be recognized as a real pioneer in several important lines of investigation, and notably in the study of individual differences, which has reached such a pitch of development in our mental testing methods.

What then is the nature of this Experimental Psychology, and what is its relation to General Psychology? Let us begin with the answer to the second question. In its development, as we have indicated, Experimental Psychology has been to some extent separate from, and independent of, General Psychology. During last century General Psychology was closely connected with speculative philosophy. In consequence it was largely what one might call a "fireside" psychology. That is to say, an individual, in order to study psychology, had merely to sit by the fireside in his study, turn his thoughts inwards, and observe what went on in his own mind. Needless to say, if he had some pet philosophical theory to support, he had little difficulty in finding the necessary support in the results of his observation. For this psychology the world of experimental science was an entirely alien world. In his heart of hearts the philosophical psychologist could not help being aware that he sought the agreeable rather than the true. The coming of Experimental Psychology has, however, reacted on General Psychology, the philosophical psychologist tending to disappear, and the scientific psychologist to take his place. Hence the General Psychology of the present is no longer derived from speculative philosophy, but is largely founded upon experimental methods and experimental results. To regard Experimental Psychology, therefore, as separate from, and having no connection with, General Psychology is at the present time an entirely erroneous view. Experimental Psychology is an essential part of General Psychology. A psychology without the experimental part is to-day an anachronism.

Experimental Psychology has grown up from a desire to study under more exact and standardized conditions problems which are really problems of General Psychology. The standardizing and control of conditions is the function of experiment in science. The general result has been the transforming of psychology as a whole from a largely speculative science—save the word—to a science empirical and practical, whose facts can be verified, as in the case of physics and chemistry, by observation carried out under definite and rigorous conditions.

The answer to our first question is already indicated. The

chief method of procedure in psychology may now be said to be similar to that of other recognized sciences. It is in respect of its subject matter, not in respect of its method, that psychology differs from the other sciences. The physical sciences study the facts of the material universe. The phenomena observed are the phenomena of the movements and interaction of material particles in space. On the other hand psychology is mainly concerned with mental or psychical facts. Desires, emotions, thoughts, feelings are typical phenomena for psychological investigation. The difference is a difference between the material and the immaterial, between a world in which the C.G.S. system of physical units applies, and a world in which it does not apply. Between psychology and the other biological sciences the difference is not quite so marked. Psychology like the other biological sciences studies the phenomena of life, but these phenomena are regarded on their inner aspect. Apart from this difference of subject matter, and the special modifications of scientific method which it involves, there is no essential difference between psychology and any other experimental science.

The Psychological Experiment.—The real character of Experimental Psychology will become clear if we consider for a moment the nature of the psychological experiment. All science is founded on the observation of facts. Observation in psychology may take either of two directions. We may observe and report our own feelings and mental activities, in which case we have self-observation; or we may carefully watch the behaviour of others, which may give us a clue to the processes going on in their minds. Self-observation, or the looking into our own minds, must be supplemented by the data obtained from observing the behaviour of others; our results will otherwise be limited in value and scope, and will be biassed by our individual idiosyncrasies, prejudices, and the like. Conversely the reports of others, and our observation of others, can only be interpreted in the light of our own individual experiences. Self-observation is the complementary process to the observation of the behaviour of others.

Self-observation, or introspection as it is more generally called, is apt to be considered as a mode of mental exercise involving particular difficulty, and the student who begins a course in Experimental Psychology is inclined to look on the recording of his own experiences as a task of which he is incap-

able. Yet there is nothing mysterious about introspection. It is something we are doing almost constantly in our everyday life. Whenever we remark that we are hungry, or have a headache or that we are feeling happy or depressed, we are really observing and reporting our own experience. This is certainly not the systematic, trained introspection of the psychologist, but in essence it is the same process, though in a more rudimentary form. When we introspect as psychologists, we are merely carrying out in a more perfect way a mental process which is of everyday occurrence. When we introspect in the course of an experiment, we are merely giving expression under special conditions to the thoughts, feelings, and resolves we observe in ourselves.

Introspection in experimental procedure is always directed towards a certain problem, and controlled along special lines. It may be that we are interested in imagery, and we arrange the conditions of the experiment so that the individual acting as subject has to record whether the image in his mind, of a picture, let us say, which has been previously shown him, is a clear and distinct one. Can he see all the items in the picture with equal vividness, or are some seen better than others? Do all the colours in the picture stand out prominently, or are certain colours less vivid than others? Or we may be interested in the affective, or feeling, side of our experience, and we may arrange an experiment to throw light upon this. Certain colours may be shown in succession, and the individual may be asked to record the subsequent feelings of pleasantness or unpleasantness, which they evoke, and whether the feeling for a particular colour can be traced to any association of that colour with something in his experience to which the feeling really attaches. In these two examples of experimental procedure interest would be centred exclusively on the introspection of the subject.

It has been frequently asked whether systematic introspection is really possible. Can we turn back, as it were, upon ourselves, and look into the processes which are going on in our minds? If we are feeling angry, can we examine our anger; can the mind be divided into two parts, the one experiencing the emotion, the other examining the experience? Is it not the case that we destroy the mental process we wish to observe immediately we commence to analyse it? Arguing along these lines, some psychologists have come to the conclusion that all

our introspection is in reality retrospection. With practice, however, and where the mental process is neither too intense nor too transient, the mind, or rather the attention, can oscillate between the actual experiencing of the emotion, feeling, desire, or volition, as the case may be, and the more or less systematic analysis of that experience. But in some cases, from the nature of the experiment, it may be inconvenient to interrupt it at every step to record one's introspection. In such cases recourse may be had to the more indirect method of retrospection. We may ask the subject to write a report of his experiences at the end of the experiment. Such a method does not yield results so satisfying as the more direct introspection, since we are compelled to rely on the trustworthiness of the individual memory. In any case such retrospection necessarily assumes a measure of introspection during the event. The two methods are thus closely allied, and together they furnish the only means by which the chief source of psychological data, that is the individual's own experience, can be investigated.

In some experiments our main interest may lie, not in qualitative, but in quantitative results. We may then relegate the introspective observations to a secondary place, and concentrate our attention on the accumulation and compilation of statistical data. Yet it is inadvisable wholly to ignore the subjective aspect, for the records of the subject may throw considerable light upon some vagary in the objective data, which otherwise might appear quite unintelligible and inexplicable. Hence the report of the subject should as a rule accompany, and be employed to interpret, the objective results recorded by the experimenter.

Hitherto we have been speaking of observation so far as it concerns ourselves. A considerable field also offers itself for study, when we turn to the observation of the behaviour of others, for, as we have already seen, we can get a psychological interpretation of this behaviour on the basis of our own experience. For example, if we see a man clench his fists, draw himself up to his full height, his whole bearing and attitude showing defiance, and his eyes, as the novelists say, flashing fire, we conclude that he is angry, and we have direct knowledge of that inner state from our own experience. If we observe an individual with drooping mien, his step weary and tired, and his whole demeanour suggestive of mental apathy and general lassitude, we infer that he is feeling listless and depressed. By

carefully noting an individual's general tendencies one can often foretell his behaviour when placed in a certain environment. One can say what he will do, how he will act, and foresee the attitude he will take up towards a situation.

In the same way the behaviour of an individual during an experiment very often furnishes valuable data to the experimenter. This is particularly the case in word-association experiments. It is a well-known fact that words or ideas, which frequently occur together, become closely associated in the mind, and the presence of one of them in consciousness is sufficient to suggest all the other words or ideas with which it is intimately connected. An important type of experiment is based on this fact. A list of words is prepared for use as stimulus words, and the subject is asked to reply to each word separately with the first word it suggests to him. It may happen that the stimulus words connect with some former incident in the life of the individual, or they may bring up some previous emotional experience. The responses certainly indicate in many cases the general trend of the subject's thoughts and interests. Those things which touch the subject intimately may be made evident, if at the same time the external behaviour of the individual is observed. We may note a marked hesitation in giving a response, accompanied by a fluster and a general air of uneasiness. In such a case there can be little doubt that the stimulus word is connected with some emotional experience, the expression of which the subject is endeavouring to inhibit. In fact it has been asserted that, to any one who has eyes to see, our slightest gestures, of which we may be totally unconscious, reveal our inmost thoughts and character. They are indications of what is passing in our minds, it may be consciously, it may be unconsciously.

The objective type of experiment, as we may call it, is specially important in the field of animal psychology. Animal psychology has always been an interesting and important branch of psychology. From the study of the lower animals we have learned, and may learn, much that throws light on the workings of the human mind. In animal psychology field work will always be valuable, that is the study of the habits and behaviour of animals in their natural environment, but recently the tendency has been more and more to observe animals under strictly controlled experimental conditions, and for some problems this is the only kind of observation that offers any promise

of successful solution. For example we may be interested in the process and rate of animal learning. We devise an experiment in which an animal has to carry out a process of learning under our observation. We may use, say, the maze method. In this experiment the animal has to find its way out of a maze in order to reach its food. We record the attempts it makes, note the errors, and their gradual elimination with the increasing number of trials, observe the time taken in each successive trial, and so on. The results of such experiments with animals have often thrown considerable light on human learning.

The danger which requires to be guarded against in animal experiments is with respect to the interpretation we place upon our results. We cannot assume that the animal is having exactly the same experiences as a human being would in similar circumstances, and we cannot verify by appeal to introspection. Hence the experiment must be more purely objective than it ever need be with the human being. Our observation must be patient, detailed, and unprejudiced. With respect to interpretation it is better to under-estimate than to over-estimate the level of intelligence involved in what appears to be behaviour similar to that of the human being. In spite of the difficulties, however, wonderful results have been achieved in this field, and it must also be remembered that investigations can be carried out on animals, which might not be conveniently or safely carried out on man.

Some further general remarks on experimentation in psychology will not be out of place. In all psychological experiment it is absolutely necessary that the individual who is acting as subject should approach the investigation in the proper attitude. The experiment is useless if the subject comes prepared to expect certain results, since his mind is unduly biassed from the start. He must assume an impartial attitude, and endeavour as far as possible to obtain a clear, unprejudiced result. On the other hand there must be interest in the experiment, a whole-hearted interest and keen concentration, or the results will be of little value. An indifferent attitude is entirely out of keeping with all experimental work, but particularly does this hold good in psychological experiments. It is also essential that the aim of the experiment be clearly understood, and, where apparatus is involved, an intimate knowledge of the working of the apparatus is necessary on the part of the experimenter for the proper conduct of the experiment. Adequate

knowledge of the procedure should be tested and secured beforehand in a practice series preceding the experiment proper. If an experiment continues over more than one sitting (and an hour and a half should never be exceeded) what is known as a "warming-up" series is also essential at the commencement of each work-period.

It must further be realized that an experiment, simple though it may appear, is really part of a larger scheme. It involves the isolation and study of one factor, or of one condition, and the relation of the single experiment to the larger plan should be thoroughly grasped. Otherwise the experiment may appear insignificant and useless. "To plan an experimental attack upon any problem in psychology we must first reduce it to its simplest terms." [1]

There is another point that must be attended to in all experimental work. Once a method has been decided upon, it must be adhered to rigidly. No modifications are allowable until the experiment as such has been completed. In particular the experimenter must on no account try to puzzle the subject by the insertion of arbitrary catch experiments. If that is done, it will only cause the subject to become flurried, and the data obtained will be of little value.

It can be inferred from what has been said that two persons are necessary to the carrying out of any experiment. One acts as experimenter, the other as subject. When the experiment has been completed with the one subject, it is usual for experimenter and subject to change rôles, and for the experiment to be repeated with the new subject. The experimenter is always responsible for the conduct of the experiment; he it is who controls the apparatus, and who guides the investigation throughout. If any particular method is to be adopted, such as one of the psycho-physical methods, he alone is responsible for seeing that it is adopted and used correctly. The subject is immune from worry as regards these considerations. His rôle, however, is not that of a passive spectator, but of an active participant. He must co-operate with the experimenter, giving of his best in respect of that part of the experiment which he is called upon to perform. He alone is aware of what is going on in his mind, although the experimenter by observation of the subject's external actions and gestures may gain valuable information.

[1] J. B. Watson, *Psych. from the Standpoint of a Behaviorist.*

Since the introspection of the subject may form a most important part of the results of the experiment, it is evident that his mental and physical condition must be carefully noted and recorded. Fatigue, either mental or physical, is not conducive to results of the best quality, unless where fatigue is the condition under investigation, when the results obtained from a fatigued subject may yield valuable data if compared with results obtained from the same observer in a fresh condition. In any case the state of health of the subject should always be noted at the beginning of each work-period. When recording introspection it is best to make it as detailed as possible. It is better to err on this side, than to have the subjective report meagre, scrappy, and relatively useless. Let every little fact and incident, which may throw light upon the matter under observation, be noted down, however trivial it appears. The most satisfactory work is done when two individuals carry out an investigation in perfect harmony, and without anything like a competitive spirit developing, for unless a friendly and sympathetic attitude exists between experimenter and subject, great difficulty will be experienced in carrying any experiment to a successful issue.

As we have already indicated, psychological experiments may be either qualitative or quantitative. In a qualitative experiment we seek to know what the phenomena are, in a quantitative to apply some kind of measurement to them. As Titchener has put it, "the object of the qualitative experiment in psychology is to *describe;* the object of the quantitative experiment is to *measure*."[1] It is evident that the qualitative experiment is in general dependent to a much greater extent on careful and detailed introspection; the quantitative on the other hand is dependent to a greater extent on careful arrangement of the experiment on the part of the experimenter. Elementary experimental work in psychology is nearly always qualitative, the quantitative demanding a technique and experience which we can hardly expect in the beginner.

The Psycho-physical Methods.—Various technical methods characteristic of the science of psychology have been developed to meet the needs of quantitative experiment. Of these the most important and the most characteristic are the psychophysical methods, which we owe, as we have seen already, to

[1] *Experimental Psychology*, vol. 2, pt. 1, p. v.

Fechner. These methods are mainly applicable to sensory experience, but many of the principles involved in their use are important principles applying to quantitative experimentation in psychology as a whole. All sensations have three aspects or attributes—quality, intensity, and duration or protensity. Some sensations have a fourth attribute which may be called extensity, or in some cases possibly voluminousness. The quality is the attribute which in a peculiar sense makes the sensation what it is—a sensation of blue, rough, sour, as the case may be. The intensity is the "how much" of a particular quality, the protensity is the "how long in time," and the extensity the "how big." The attributes of protensity and extensity are the basis of our sensory experience of time and space respectively.

Now intensity, protensity, and extensity are all quantitative aspects of sensation, and it is to the investigation of these that the psycho-physical methods are particularly applied. The problems which arise belong to two main categories. On the one hand they have to do with the limits of sensibility, either absolute or relative. On the other hand they have to do with the conditions of apparent equality, or the conditions under which constant errors are produced in the estimation or reproduction of intensities, magnitudes, and the like. The first category is the more important. We may seek to determine what is the smallest intensity of stimulus that will produce a sensation, or the smallest difference in stimulus that can be apprehended as a difference. Problems of this kind are known as problems of the threshold—absolute or differential. Some of them are of very great practical importance. For example, in determining an individual's acuity of hearing or vision we are concerned with a problem of absolute threshold; in testing an individual's pitch discrimination we are concerned with a problem of differential threshold.

The standard psycho-physical methods are three in number, and are usually designated: the Method of Limits, the Method of Right and Wrong Cases, and the Method of Mean Error. The first and second are the methods usually employed in studying problems belonging to the first category, the second and the third in studying problems belonging to the second category. This may seem to suggest that the Method of Right and Wrong Cases is the most universally applicable and most useful of the methods. As a matter of fact it is the method least frequently

employed. Theoretically it is the most universally applicable; practically it involves the expenditure of so much time and labour that investigators avoid its use whenever possible. Many psychologists, indeed, hold that the exactitude of measurement which it professes to give is illusory.

(1) **The Method of Limits.**—The procedure in the method of limits is comparatively simple, and consequently it is the method most frequently employed for threshold determinations. The problem in these cases is to find the stimulus, or stimulus difference, which yields a sensation, or a difference, that is just noticeable and no more. If our problem is of the first type, we begin with a stimulus which yields a clearly noticeable sensation, and reduce its intensity (if we are dealing with intensities) by small and regular gradations, until the sensation is no longer felt. For example, if R be the initial stimulus, and d be the gradation we employ, we should have the experiment going like this:

R	subject says "yes"
$R - d$	do.
$R - 2d$	do.
. . . . .	
$R - (n - 1)d$	do.
$R - nd$	subject says "no."

If we depended on this series alone, then we should say that the threshold lay between $R - (n - 1)d$ and $R - nd$, and we should take it halfway between them; that is, the average of these two values would be taken as the threshold.

If it is a difference threshold we are investigating, we use two stimuli, a standard (S) and a variable (V), but otherwise the procedure is the same. Let us assume we wish to find the threshold above the standard. We begin with a variable above the standard, and easily distinguishable from it, and diminish it by gradations until the subject fails to perceive any difference. Such an experiment would go like this:

S	V	subject says "different"
S	$V - d$	do.
S	$V - 2d$	do.
. . . .		
S	$V-(n-1)d$	do.
S	$V - nd$	subject says "same."

If we relied on this one series the threshold would be taken as the difference between S and the average of $V - (n - 1)d$ and $V - nd$.

The objections to stopping the experiment at this stage are fairly obvious. The judgment of the subject will certainly be biassed by the fact that he is dealing with a continuously descending series, and therefore knows that a point will come sooner or later at which he will cease to be able to feel the sensation or apprehend the difference. In any case the investigator is bound by the principles of scientific procedure to make sure that the judgment of the subject is not influenced by such a factor. Hence a descending series must always be followed by an ascending series. The experimenter begins below the threshold, and increases intensity or difference by gradations as before, until the subject answers "yes" or "different" as the case may be. To get the threshold from the two series—descending and ascending—we take the mean of the last value on the descending for which we get the answer "yes" or "different" and the last value on the ascending for which we get the answer "no" or "same." In all cases, when the judgment of the subject changes, the experimenter ought always to go on to the next value in order to confirm.

Such is the method of limits. It is characteristically liable to certain errors, some of which are very difficult to eliminate. The errors incident to psychological experiment may be classed in three groups (*a*) constant errors; (*b*) variable errors; and (*c*) accidental errors. It will repay us to consider briefly these three types of error at the present juncture. The method of limits is liable to all three, but it is the second group that is more particularly characteristic of it.

Let us begin with *accidental* errors. The errors we call "accidental" are errors due to unknown causes, and usually a large number of unknown causes. They are the errors of "observation" which we meet in all quantitative scientific work. In the long run these errors show what we regard as a purely chance distribution. That is to say they occur as frequently in one direction as the other, and the frequency of occurrence of any error is inversely proportional to the magnitude of the error. In order to eliminate such errors, therefore, we take as many observations as possible, and the more observations we take the greater will be the accuracy of our mean result. With a sufficient number of observations the accidental

errors in one direction cancel those in the other direction. Hence, in the case of the method of limits, we ought not to content ourselves with a single descending and a single ascending series, but should take as many as possible of each—say twenty.

The *constant* errors differ from the accidental errors in that they always occur in the same direction, and they are due to causes which are relatively few, and known. It may be asked, why they are not avoided. The answer is that they cannot be avoided under the conditions of the experiment. Thus, if we are comparing two stimuli which cannot be presented simultaneously, it may make a difference which we present first. If the two stimuli can be presented simultaneously, they cannot be presented at the same point in space, and it may make a difference which is to the right or the left, above or below. Errors due to such causes—*time* and *space* errors, as they are called—and constant errors in general are eliminated by taking as many observations under the one condition as under the other. By taking the mean of all the observations we clearly eliminate the constant error. Not only so, but we can in this way calculate the amount of the constant error. Suppose we are dealing with a time error. Let q be the amount of this error, p and p' the results got with the two time orders respectively, and x the true result with the time error eliminated. Then, since the direction of the time error is reversed in the second series,

$$p = x + q \text{ and}$$
$$p' = x - q,$$

hence $x = (p + p')/2$, as already seen,
and $q = (p - p')/2$.

We are left with the *variable* errors. These are errors depending on the trend or attitude of the subject, and varying in the course of the experiment. Thus, as any particular piece of work goes on, the subject becomes more practised, until the maximal practice effect is reached. At the same time, the longer the work goes on the more fatigued the subject becomes. Practice and fatigue are therefore two sources of variable error, which must be guarded against. They will tend to counteract one another, but we cannot assume that they will balance one another. Hence we must take precautions against the errors that will arise. We take precautions against fatigue by seeing that the experimental sitting is never so long as to produce

appreciable fatigue. The practice effect is not so easily dealt with. Theoretically we could eliminate it by seeing that the subject was sufficiently practised, that is, was already expert, before we began to record our observations. Under such circumstances the practice gain would be inappreciable. Practically, however, we find that the elimination of the practice effect in this way is not so easy as it seems, the process of becoming expert being much slower, and as we shall see later, more irregular, than we should at first suppose. In most cases the only thing we can do is to take the practice effect into account, and at the same time arrange the experiment so as to balance it against itself, as, for example, by giving descending and ascending series equal advantages as far as practice is concerned.

Other variable errors arise in connection with the method of limits from the progressive nature of the series. In a descending series the subject knows that the intensity of the stimulus or the magnitude of the difference is decreasing. Expectation of the point at which he will cease to experience the sensation or notice the difference may lead him to anticipate this point. Analogous conditions are of course present in the ascending series. On the other hand, the subject may become accustomed, or habituated, or accommodated to a certain form of judgment, and the point at which the judgment should change may thus be postponed. As in the case of practice and fatigue, expectation and accommodation will tend to counteract one another, but we cannot assume that they will balance one another. We can vary their effects by varying the length of our series. That is to say we can start at different points in the different series, but even then we must to some extent rely on the goodwill of the subject, and have the subject's introspection to guide us.

In order to avoid the errors due to expectation and accommodation, the method of limits has been modified in various ways. One might suppose that the introduction of "catch" experiments would eliminate these sources of error. Unfortunately "catch" experiments tend to change the whole attitude of the subject, and produce with some subjects much more serious errors than those we are seeking to eliminate. McDougall, however, has used a modification of the method of limits with the introduction of "catch" experiments, which appears to be free from the graver defects involved in their indiscriminate and arbitrary introduction. This modification is known as the

Method of Serial Groups. The procedure is very simple. Let us suppose we are determining a difference threshold. In place of presenting each pair for comparison once, we present them five (or ten) times making a group of presentations, and in the same group we give five (or ten) "catch" experiments mixed in haphazard order with the real experiments. The subject's judgments are noted as right or wrong, and in the record the real experiments are kept separate from the "catch" experiments. When all the judgments in the real experiments are correct we go on to the next value. If one error is made, we repeat the series, and we take as our threshold the lowest value in the descending series that gives 80 per cent. correct judgments. The average of this and the analogous value obtained from the ascending series yields our final result. This method is an excellent one, and there is no doubt that it eliminates variable errors due to expectation and accommodation, but the method of arriving at the threshold is unfortunately somewhat arbitrary.

Another method of meeting the difficulty is to take the series in haphazard order, preserving the serial arrangement in our record. The objection to this is that we are virtually abandoning the principle of the Method of Limits, and adopting that of the Method of Right and Wrong Cases. Hence it is very doubtful whether our results reached in this way are really comparable with results reached by the employment of the true Method of Limits. It is certain that the attitude of the subject is very radically altered.

(2) **The Method of Right and Wrong Cases.**—This method is sometimes known as the Constant Method. As we have already pointed out, it is the most elaborate of all the methods, and theoretically the best. Practically its use is circumscribed by the length of time the experiment takes, and the somewhat difficult and complicated mathematical treatment which the results require. It can be employed for the same problems as the Method of Limits, but it differs from that method in three respects. In the first place a much smaller range of variables is used. In the second place each variable is presented a great number of times. In the third place the arrangement of the variables in a series is haphazard. The threshold is defined as that value for which the chances are equal that it will be and that it will not be apprehended. If then in a difference threshold experiment we get a variable which is distinguished from

the standard on 50 per cent. of the occasions on which it is presented with the standard, we take this as the threshold, since the chances of being right and wrong in its discrimination are exactly equal. For variables on the one side the chances will be greater that they will be discriminated, than that they will not; for variables on the other side the chances will be less. Owing to the fact that the threshold is defined in this way, it is evident that its calculation involves and depends upon the mathematical theory of probability, and this is the source of the difficulty in the treatment of the results.

The procedure itself is not difficult. To begin with the threshold is roughly determined by the Method of Limits. Then values round about that are taken, say seven or nine in all, and each of these presented a sufficient number of times. For the presentation we arrange series of fourteen or eighteen, in which each variable occurs twice, but the order is haphazard. Fifty such series might be taken altogether, which would give a hundred presentations for each variable. The results are then tabulated giving the percentage of discriminations under each variable. From these results, using mathematical methods based on the theory of probability, we calculate the value for which the chances are equal that it will, and will not, be discriminated, that is the variable which we may expect to be discriminated in fifty out of the hundred presentations.

Where two stimuli are being compared we must see to the elimination of constant errors. Let us take for illustration an experiment to determine the difference threshold for lifted weights. We take as standard a weight of, say, 2000 grammes, and nine variables differing from one another by 50 grammes, on both sides of the standard. The experiment is arranged so that the weights may be lifted successively from the same place, at the same rate, and to the same height. This can be done by lifting from a rotating table, in time to the beating of a metronome, and up to a string stretched across between the uprights of two retort-stands. By lifting from the same place we have eliminated the space error, but since the weights are lifted successively there is still a time error involved. Hence we must arrange that the comparison be made as often with the standard first as with the standard second. The subject is directed to compare the two weights, and give his judgment by saying that the second is greater, equal to, or less than the first. There are eighteen lifts in each series, each variable being given

twice with the standard in haphazard order. To make the experiment sufficiently brief to be carried out in an ordinary experimental course, we should take ten series with each time order. These ought to be arranged so that neither time order gets any advantage from practice. For example, if our first series is with the standard first, our next two will be with the standard second, our next two with the standard first, and so on, our last being with the standard first.

To make full use of the data obtained from such an experiment, elaborate mathematical treatment is, as we have seen, necessary. For that the student must be referred to more advanced text-books. An approximate result, however, may be obtained without any very serious mathematics, by interpolating a value corresponding to 50 per cent. greater or 50 per cent. less, according as we desire the upper or the lower threshold. Thus if 2100 is judged greater in 60 per cent. of the judgments, and 2050 in 45 per cent., we interpolate a value corresponding to 50 per cent. by means of the formula :

$$\frac{2100\,(50 - 45) + 2050\,(60 - 50)}{60 - 45}.$$

This gives us 2066·6, and the upper threshold is therefore 66·6 for the particular time order we are dealing with, i.e., standard first. If for the other time order it is 75, we get our true threshold by the average of these, 70·8, and our time error by the procedure already described. The time error in this case would be 4·2. A time error is taken to be positive when it tends to increase the value of the stimulus first presented. It is therefore positive in this case. The same procedure, taking the judgments less in the same way, would give us the lower threshold. The objection to this method of calculating the threshold is that we are entirely neglecting a large portion of our data.[1]

Certain characteristic phenomena of the Method of Right and Wrong Cases deserve some notice. In some cases the judgment of the subject is not based on the comparison of the stimuli to be compared. This may happen in several ways. When a large difference immediately precedes a small difference, or vice versa, or when a heavy variable immediately precedes a

[1] For a formula due to Spearman, which does not require the use of the elaborate mathematics of the theory of probability, see *Brit. Journ. of Psych.*, vol. ii., p. 227.

light variable, or vice versa, the contrast effect may influence the judgment. More generally the judgment may be based on comparison of the variable, not with the standard, but with the variable in the preceding experiment. This is what is known as a *side comparison.* Then again the subject may judge on the basis of the *absolute impression* of a certain variable as heavy or light. Phenomena of this kind are inevitable, but careful introspection on the part of the subject ought to enable the experimenter to take note of them. One other point! It not infrequently happens that the results actually got show what are known as "reversals." When we get a smaller percentage of "greater" judgments with the larger variable than with the variable next below it in magnitude, we have what is known as a "reversal of the first order." Such reversals always indicate defect somewhere in the conduct of the experiment, and unreliability in the results. "Reversals of the second order" are not so important, and are rarely absent. In this case the rate of increase of "greater" judgments shows a diminution in place of an increase, with increasing difference from the standard. Such reversals are simply indications of the complexity of the factors we are dealing with, and of the irregularity of the results in psychological as contrasted with physical experiment.

(3) **The Method of Mean Error.**—The third of the psychophysical methods is sometimes known as the Method of Production. It differs from the other two, not merely in the procedure adopted, but also in the kinds of problems for which it is employed. We use the Method of Mean Error to investigate the conditions of apparent equality, the conditions under which the estimation or reproduction of intensities, magnitudes, and the like, is affected by constant errors, and the direction and magnitude of the errors. With respect to procedure, the subject is required to alter the variable, so as to make it equal to the standard (or bear any given relation to the standard). Let us suppose that the subject has to change a variable length till it is equal to a fixed standard length, the two lengths being simultaneously before him, and provision being made for a simple way of changing the variable length. In this case there will be a space error, since the two lengths cannot be simultaneously in the same place. If they are on the same horizontal level, one will be to the right and the other to the left, and the customary measures must be taken to eliminate and calculate the space error. The same measures will of course be taken

to eliminate and calculate the effect of any other constant source of error. A sufficient number of experiments will be taken to eliminate also any accidental errors. When we take the mean of all the subject's estimates, we have a value which we can take as equal to the standard for that particular subject and under the particular conditions. This is the value which the subject is, as it were, trying to hit every time. The average of his deviations from this we call the "mean variable error," which is merely an error of the nature of errors of observation in the physical sciences. The difference between this value the subject is trying to hit and the standard, however, is an error of an entirely different sort. It is known as the "crude constant error." The main object of the experiment and the method is to determine the constant factors which are producing it, and the proportion of the error to be attributed to each factor. The principles which guide our procedure have been already discussed in dealing with constant errors.

The Measurement of Time.—Certain technical methods employed in the measurement of short time intervals must also be briefly described. The measurement of time is often of very great importance in psychological experiments. Where we have to measure a considerable period—ten seconds or more—any ordinary stopwatch is sufficiently accurate for most purposes. For shorter periods we must employ more delicate apparatus. Special stop-watches are made, measuring to a tenth of a second or less, but for time intervals less than a second no stop-watch is capable of giving anything but a very crude measure. For the accurate measurement of all such intervals some type of chronoscope must be employed. Several types of chronoscope have been devised for psychological purposes. The one most frequently found in the psychological laboratory is the Wheatstone-Hipp Chronoscope. This gives readings in thousandth parts of a second. It consists of clockwork driven by a weight, and controlled by a spring vibrating a thousand times a second. There are two dials, one reading in tenths and the other in thousandths of a second. The hands are engaged with the clockwork by a clutch operated electrically by means of electromagnets. What is actually measured is the time during which a current passes, or during which a current is interrupted. Hence in using the chronoscope it is necessary for us to arrange that the interval of time we wish to measure is simultaneous with the making or breaking of an electric circuit.

The Schultze chronoscope is a modification of the Wheat-

stone-Hipp. Another chronoscope, the d'Arsonval, does not differ in principle except for the fact that the clockwork is driven by a spring. It only gives readings, however, in hundredths or two-hundredths of a second. The Phonic Motor chronoscope and the Johns Hopkins chronoscope are motor driven. They are practically identical except in name and in place of origin, the one being British[1] and the other American. The motor is of the synchronous motor type. It is ten-pole, and the interruptions of the current are made by a tuning-fork or a vibrating lamella. The units are determined by the rate of interruption, a tuning-fork of 100 vibrations per second giving readings in thousandths. As in the other chronoscopes the hands are engaged and disengaged by an electro-magnetic clutch mechanism.

The most general method for the measurement, as distinct from the direct reading, of short time intervals is by means of a graphic record. The usual way of obtaining this is by using a smoked drum. A metal cylinder is rotated by clockwork or by a motor. Paper is fastened round this cylinder, and given a coating of soot by means of a smoky flame. On this smoked surface the start and finish of the interval we wish to measure is recorded by means of a light marking point attached usually to an electromagnet. Or we may record the whole course and direction of some process, the time relations of which we wish to ascertain, as, for example, pulse, breathing, and the like. Along with this record, and underneath or above it, we place our time record. When the time intervals are relatively long, we get a sufficiently accurate measurement by marking seconds, half-seconds, or fifths of seconds. When the time intervals are short we mark the vibrations of a tuning-fork, which vibrates fifty, a hundred, or two hundred and fifty times a second, as the case may be. In fact, it is clear that we may obtain even finer measurements by recording the vibrations of forks or lamellæ of still greater frequency of vibration. The ordinary device for transferring the time units to the smoked surface is by a marker magnet and electric circuit, the circuit being interrupted every second, half second, hundredth of a second, according to the time unit we are using. To make the records permanent, and enable us to measure the times at our leisure, we cut the paper off the drum, and pass it through a dish containing spirit varnish.

[1] The Heythrop Phonic Chronoscope is the most recent of this type.

The Statistical Treatment of Data.—In order to eliminate accidental errors, we have seen, it is necessary to take a number of observations sufficiently great to warrant us in assuming that the errors in one direction will be cancelled by the errors in the other direction. We thus get a number of individual results, each professing to measure the same thing, and the question arises as to which of these results we are to take. The same kind of situation arises in the physical sciences whenever we attempt to get a very precise measurement. We have hitherto assumed that we get the true result by taking the average or mean of our observations. This is tantamount to assuming that the individual deviations from this value are distributed as they would be if the distribution was entirely due to chance. The conception of normal distribution is an important one in psychology, and in the biological sciences generally. Normal distribution is a distribution which presents the appearance of being due to pure chance, and which therefore accords with a distribution deduced from the mathematical theory of probability. Let us imagine a not too expert rifleman aiming at the centre of a target, and shooting an indefinite number of times. If no constant factor is influencing the direction of the shots, we shall find them distributed all over the target, but in a characteristic way. They are clustered much more closely about the centre, and the farther we go from the centre the fewer shots we find, until we reach a distance within which all the shots have fallen. The rifleman is like an observer trying to make an accurate measurement. The distance between the centre and the place where any shot hits the target is analogous to an error of observation or measurement in a particular case. If we plot a curve showing the frequency of occurrence against the magnitude of the errors, we get a curve like that shown in Fig. 1.

The curve indicates that the frequency of an error varies inversely with its magnitude. The actual relation, as deduced from the mathematical theory of probability, is given by the equation to the curve, $y = ke^{-h^2x^2}$, where x is the magnitude of an error, and y the frequency of its occurrence. Theoretically an error of infinitely great magnitude may occur, but it occurs infinitely seldom. Practically there are definite limits dependent on the accuracy of the measurements, and the magnitude of h in the equation is an indication of this accuracy, or of the scatter of the individual measurements.

Not only do errors of observation or accidental errors show normal distribution, provided we take a sufficient number of measurements, but measurements of the same character, physical or mental, in a number of different individuals show the same type of distribution, provided we have a sufficient number of individuals and they are not selected on the basis of some character related in some way to the character we are measuring. If, in either case, normal distribution is not shown, we infer in the one case a constant factor—or it may be constant factors—determining a bias in a particular direction, in the other case a selective factor—or selective factors—destroying the representative character of the group of individuals measured.

Now, with normal distribution, it is clear that the magnitude whose frequency is at the apex of the curve is the correct measurement, corresponding to an error of ± 0. It is also evident that

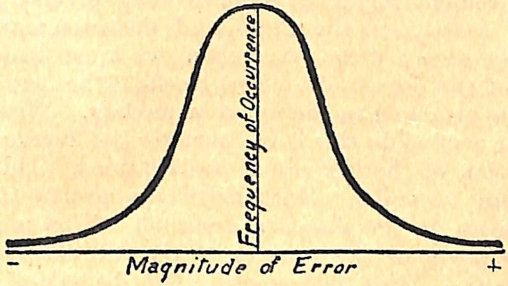


FIG. 1.

this magnitude will be the mean of all the observations. It will also be the middle value or median. Further, the magnitude occurring most frequently in a series of measurements is known as the mode. Hence, with normal distribution, mode, median, and mean, all coincide, and it is indifferent which we take as representing the result of our measurement. Actual measurements, however, rarely show more than an approximation to normal distribution. With the relatively small number of observations possible under the conditions of most psychological experiments, we could hardly expect otherwise. The question of selecting the most suitable representative value, therefore, may in certain circumstances become important. Usually the *mean* is taken. Where one or more eccentric values occur in a relatively short series, the *median* is better, since an eccentric value affects the mean in proportion to its

eccentricity, and does not affect the median any more than values that are not eccentric. Sometimes, though rarely in ordinary experimental work, the *mode* may be taken, where a great number of measurements through a relatively small range is available.

Whatever representative value is taken must always be accompanied by some indication of the extent to which it is reliable or really representative. If we revert once more to our normal distribution curve, we see that this may vary in the height relatively to the width, according as the observations are crowded close about the mean, or widely scattered. The greater the scatter the less reliable is the series of measurements as a whole. So in any series of measurements the more widely the individual values are scattered, the less significance can we attach to any representative value we obtain. Its reliability as a measurement might be said to vary inversely with the amount of scatter of the individual measurements. Hence, whenever we give a mean or median, we must also give some indication of the degree of scatter, to show the degree of significance to be attached to the mean or median. With the mean the simplest way to do this is to calculate the average deviation from the mean of the individual observations. This is known as the *mean variation.* Mathematicians prefer to calculate what is known as the *standard deviation.* This is the square root of the mean of the squares of the individual deviations from the mean. This last measure of dispersion is usually denoted by σ, and for certain purposes, as we shall see presently, it is necessary to calculate it rather than the mean variation. With the median the simplest measure of dispersion is what is called the semi-interquartile range, or—erroneously—the probable error. The median is the middle value, and the values equidistant between the median and the two extremes are known as quartiles. The difference between the quartiles is the interquartile range.

Some very important investigations, both psychological and anthropological, are based on the determination of the relation between two characteristics which have been measured in a group of individuals. This relation is indicated by what is known as the *correlation coefficient.* The theoretical basis for correlation work may be said to be Mill's fifth canon of induction. "Whatever phenomenon," he says, "varies in any manner, whenever another phenomenon varies in a particular manner,

is either a cause or an effect of that phenomenon, or is related to it through some fact of causation." This is the canon or principle of "concomitant variation." We argue then that, if two characters vary concomitantly in a group of individuals, and to the extent that they vary concomitantly, they are causally related. The extent to which the characters vary concomitantly is given by the coefficient of correlation. In the standard method for calculating this we first of all express each measurement in terms of its variation from the mean, with the sign + or − according as it exceeds or falls below the mean. The coefficient of correlation (r) is then given by the formula:

$$r = \frac{\Sigma(xy)}{N\sigma_x\sigma_y},$$

where x and y are the variations from the mean in the two series of one individual, σ_x, σ_y the standard deviations of the two series, and N the number of individuals. Other simpler formulæ may also be used. (See App. B.) Generally speaking, the simpler formulæ are sufficiently accurate for most purposes. The significance and use of the correlation coefficient will be considered later.

CHAPTER I

VISION

THE eye, which is the organ of vision, is a single sense organ in that it yields only one kind of sensation, that of seeing.[1] Our visual experiences have their origin in rays of light impinging on the retina of the eye, caused by the vibrations of the ether which surrounds us. These vibrations vary considerably in wave-length, and only certain wave-lengths affect the retina. Approximately, we experience visual sensations from ether wave-lengths between 760 $\mu\mu$ (micro-millimeter or one-millionth part of a millimeter) and 390 $\mu\mu$. The colour we know as red has the longest wave-length, violet the shortest, while the other colours fall intermediately between these two. Wave-lengths longer than those which produce the colour red (the infra-red rays) are experienced not as visual sensations but as sensations of heat: similarly wave-lengths shorter than the violet rays (the ultra-violet rays) have been shown to give rise to a chemical action which can be recorded on a sensitive plate. Ordinary sunlight can be split up into these three different kinds of rays, but the intermediate wave-lengths alone are visible to us.

Our visual sensations divide themselves into two distinct groups. On the one hand, we have the whole realm of light sensations ranging from the most dazzling white to the deepest black; while on the other hand is the wealth of all our colour sensations, reds, greens, yellows, etc. Let us consider, in the first place, the colourless or *achromatic* series, as it is called. If we were to arrange the components of this series in order from its one extreme to the other, it would take the form of a straight line extending from white through various shades of grey to black. Language fails to describe the differences in the components of this series, for it reduces them to three, white,

[1] See Appendix A for a description of the structure of the eye.

grey, and black; but we find by comparing whites, different degrees of whiteness; similarly blacks are not all identical. In fact, the number of whites, greys, and blacks possible to distinguish has been estimated as lying somewhere between 700 and 800.

The colour or *chromatic* series is more complex, and cannot be arranged upon a straight line. Newton, who investigated the physics of light, was the first to find that if the intermediate rays of the sun are passed through a prism, they are broken up into all the colours of the rainbow or spectrum; red, orange, yellow, green, blue, and violet. (Sometimes indigo is added between the blue and the violet.) This list of colour elements, it must be understood, is convenient rather than scientific, for the number of different wave-lengths in the spectrum is unlimited, and further, the number of *recognizable* wave-lengths, that is the psychological number, far exceeds seven. However, let us take the familiar colours of the spectrum and try to arrange them in some kind of serial order. If we start with red, which occurs on the extreme left of the spectrum, we find as we travel on towards the right, that the red gradually changes its colour, beginning with a very red orange until what may be called pure orange is reached. Continuing, we pass from orange to yellow through all the intermediate shades until the red has become completely eliminated. At this point a change of colour becomes visible, and as we pass from the yellow, a faint tinge of green makes its appearance. All the varieties of greenish-yellows and yellowish-greens reveal themselves until pure green is reached. Here, again, we must pause, for a new colour appears, and we find our green becoming more and more bluish until the green is totally eliminated and pure blue becomes visible. At blue our colour changes again, but this time no new colour element is added. We see our blue acquiring a reddish tinge which in the spectral series finishes incompletely in the violet. But if we continue the series through the purples and the carmines we arrive back again at our starting point in the reds, the red of the extreme left of the spectrum.

The colour series accordingly can be represented as a circular series, and the passage from one colour to another is a steady one of gradual progression. It is interesting to note, however, that the spectral series differs in two ways from the psychological series. The psychological series is a complete series including the purples and carmines: the spec-

tral is incomplete not including these colours, but stopping at the violet. Further, the red of the spectrum is not the pure red of the psychological series, but contains some yellow; the true red lies outside the spectrum altogether, somewhere nearer the carmines.

In ordinary life, we rarely see pure colours such as we see in the spectrum, but our colour sensations are always mixed with some component from the brightness or colourless series. The combination of the two series gives us our enormous number of shades and tints, about 30,000 in all.

If the solar spectrum be examined, it will be found that it does not appear continuous, but it is crossed here and there by minute parallel lines. These were first described by Wollaston in 1802, and in 1814 Fraunhofer mapped them out carefully on a spectral chart. These Fraunhofer lines, as they are generally called, are of great service in all colour work, for they are invariable in position. Consequently, they serve as lines of reference and also are convenient points for marking out the limits of the different colours. The names of the alphabet from A to H have been given to the principal lines, and these have been associated with different regions of the spectrum. Helmholtz has analysed the spectrum in the following table:—

Line.	Wave-length in $\mu\mu$.	Colour.
A.	760·40	Extreme red.
B.	686·853	Red
C.	656·314	Junction of red and orange.
D.	$\left\{\begin{matrix}589{\cdot}625\\589{\cdot}024\end{matrix}\right\}$	Golden yellow.
E.	526·990	Green.
F.	486·164	Cyan blue.
G.	430·825	Junction of indigo blue and violet.
H.	396·879	Limit of violet.

Change in wave-length, accordingly, produces a change in colour, or in *hue* or in *tone*, but the correspondence between them is not constant. At the two extremes the hue changes very slowly and beyond a certain limit no difference is noticeable. In the centre, however, round the yellows and the blue-greens, the colour tone undergoes a rapid change.

But a further difference is apparent in the colours of the spectrum. They differ greatly in *brightness* or in luminosity. The point of maximal brightness lies in the yellow region somewhere near the D line, and a continuous decrease in brightness takes place on either side of it. Violet, in fact, is the darkest

colour of all. Some claim that this brightness value of the spectral colours is a distinct attribute which has no correlate in the physical world. The one colour is simply darker or brighter than another. Others assert that the brightness value depends upon the intensity of the stimulus which, in turn, varies with the amplitude of the light waves. However that may be, it has been shown that if the intensity of the stimulus is increased beyond a certain point, the colour tone changes, red, orange, yellow acquiring a yellow tinge, blue-green, blue, and violet approximating to blue, while green passes directly into a light grey. If the intensity is still further increased, all the colour sensations are replaced by colourless ones.

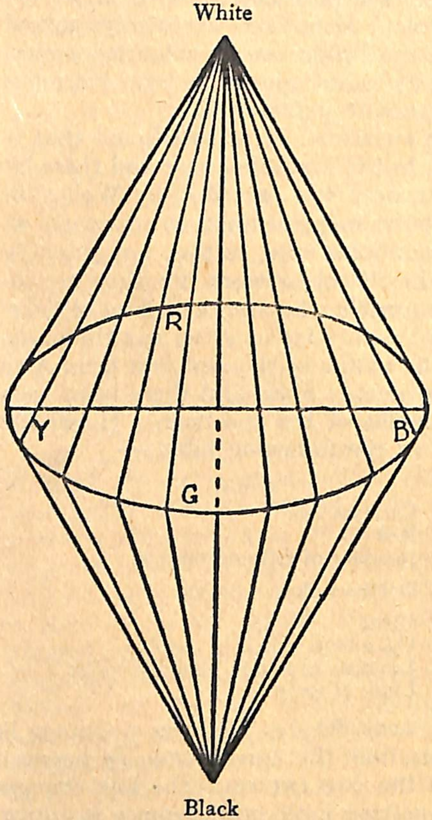


FIG. 2.—Colour Cone.

Finally, the pure spectral colours, as we have already indicated, may be mixed with some component from the black-white series. The more white light they contain, the less *saturated* they are said to be; a red differs from a pink in being more saturated. Colours mixed with black give us our shades, with white our tints.

These four characteristics of colour or hue, brightness or luminosity, intensity, and saturation, enable us to distinguish one colour from another.

Our colour sensations may be diagrammatically represented by means of a colour pyramid or a colour cone, as in diagram. (Fig. 2.) The colour series are represented by a series of circles,

the brightness series by a line at right angles to and passing through the centres of the colour series. A series of colours, all of the same brightness, can be represented by a circle, with the most saturated colours on the circumference of the circle. The centre of the circle is intersected by the black-white series, and accordingly represents a grey of the same brightness as that of the colours. Along any radius of the circle we may pass from a fully-saturated colour to a gradually diminishing colour until grey alone is reached.

Colours a little brighter will arrange themselves in a similar circle, though slightly smaller in dimension, above this first circle: colours slightly less in brightness similarly are represented by an equally sized circle below. The decrease in area of the circle is due to the fact that when the brightness of colours is increased or decreased, they lose in saturation. In this way circle after circle of gradually diminishing size may be built up on either side of the central circle until the apices of the cone are reached, with dazzling white at one end and a dead black at the other. This double cone represents all the shades and tints of every colour, and further shows the mutual relationship and dependence existing between the chromatic and the achromatic series. When a pyramid is used, it is four-sided with the principal colours, red, yellow, green, and blue localized at its four angles respectively.

Colour-Mixing.—The hue of any colour, as we have already seen, depends upon the wave-length which is stimulating the retina. But curiously enough, we may experience a definite colour sensation in the absence of the corresponding wave-length. All that is necessary is that wave-lengths be present simultaneously, whose average wave-length is equal to that producing the particular hue, in the same way as a wave-length corresponding to yellow and a wave-length corresponding to green striking the eye at the same time, combine in the sensation yellowish-green. In other words, the wave-lengths fuse as they are thrown together on the eye. This same principle is made use of in colour-mixing. Instead of the colours being thrown simultaneously on the eye, they are thrown alternately, but in such rapid succession that they appear to be stimulating the retina simultaneously. This is made possible by the fact that each excitation process outlasts the stimulus owing to the nature of the response of the retina. When the rotation of the colours is sufficiently increased, fusion takes place and one continuous sensation results.

From colour-mixing various interesting facts can be educed. The method employed is a simple one. The colour wheel is placed in a good light. If we wish to combine two colours, we arrange two discs of paper each cut along one radius. These are interlocked in such a way that when placed on the colour-mixer their edges will not face the direction in which the wheel is rotating and in consequence become torn. This allows the proportions of the two discs to be altered at will. The discs are then placed on the axis by means of the small holes cut out of their centres. They are then ready for rotation, either by hand or by motor. When the adjustment appears satisfactory, the sector of each disc is measured in degrees. If the discs had been of red and yellow respectively, their fusion would reveal various shades of orange, beginning with the red element strongly visible, and the yellow barely perceptible, passing through the phase where red and yellow in equal sectors produce pure orange, until the yellow becomes the predominant colour, with the red just discernible. That is, all the colour tones between red and yellow may be produced in this way, and this holds true of all adjacent colours in the spectrum. Their admixture results in all possible combinations of colour with the component colours clearly visible. For example, yellow and green give us all tones of yellowish-greens and greenish-yellows, green and blue produce greenish-blues and bluish-greens, while blue and red result in all hues of violets, purples, and carmines.

It is evident, therefore, that all the colours of the spectrum can be obtained with fewer than seven colours. The four colours, red, yellow, green, and blue, are sufficient—a fact realized in building up the colour pyramid. Further, red, green, and blue lights alone, combined in various ways, can yield all the colours. The fusion of the first produces yellow, the others are as before. These three colours are known as the primary colours, for they cannot be analysed further.

White light may be produced in various ways. A disc which contains in certain proportions all the colours of the spectrum will be found, on rotation, to appear colourless. But, again, all the colours are not essential, and if we reduce the number to the four specified above, no colour sensation will be evoked. Further, the three primary colours in themselves yield, when mixed in definite ratios, a colourless sensation. What is more interesting still is the observation that colourless sensations are educed by the mixture of special pairs of colours. It has already

been shown that if a yellow disc and a green disc are placed on a colour wheel and rotated, the resultant colour is yellow-green. The more the yellow preponderates, the nearer to yellow will be the yellow-green, and conversely the more green is predominant, the nearer to green. It will be found impossible, however, to eliminate either component. If the same yellow is taken, but this time mixed with a certain shade of blue, a totally different effect will be produced. Neither a bluish-yellow nor a yellowish-blue will be obtained, however much the discs are altered. As more blue is introduced, the yellow will become less and less saturated until no yellow is distinguishable at all. If the blue is commenced with and the yellow gradually introduced, it will result in the blue becoming less and less saturated. Between these two extremes a point will be found at which neither blue nor yellow will be visible. The one colour has cancelled the other, and a colourless sensation or a grey is produced. Such colours which when mixed in certain proportions give grey, are called complementary colours. The following are the wave-lengths of complementary colours given by Helmholtz.[1]

Colour.		Complementary Colour.		Ratio of Wave-Lengths.
Red . .	656·2	Green-blue .	492·1	1·334
Orange .	607·7	Blue . .	489·7	1·340
Yellow .	585·3	Blue . .	485·4	1 240
Yellow .	573·9	Blue . .	482·1	1·190
Yellow .	567·1	Indigo-blue .	464·5	1·221
Yellow .	584·4	Indigo-blue .	461·8	1·222
Green-yellow	563·6	Violet . .	433 and beyond	1·301

For every colour it is possible to find a complementary; black and white, although not colours, may also be regarded as complementary. Why is it, it may be asked, that blue and yellow pigments, when mixed, produce not grey, but green? The reason lies in the different constituents of pigments. A blue pigment reflects blue light, but it also reflects a little green; a yellow reflects yellow light but also green in addition. When mixed, blue and yellow as complementaries cancel each other, leaving green as the result. Similar results are obtained from

[1] Quoted from Parsons, *Colour Vision*, p. 38, 2nd edition.

other pigments. It is not that they act contrary to colour laws, but their mixture depends upon the particles of which they are composed. One writer explains the phenomenon by an illustration of blue and yellow glass.[1] The blue glass absorbs red, yellow, and orange light, allowing the blue rays to pass through and also some green; the yellow glass, on the other hand, allows the red, yellow, and orange to pass through, also some green, but absorbs the blue. If both the blue and yellow glass act together, the blue glass keeps out the red, yellow, and orange, the yellow glass the blue, while in both cases green alone is allowed to pass.

The brightness value of the mixture of a pair of complementary colours can readily be obtained by a colour-mixer. Place the two colour discs, say blue and yellow, as before on the colour wheel and adjust the sectors until a colourless sensation is satisfactorily obtained. Then measure the sectors. Still keeping the colour discs on the wheel, put in front of them two smaller interlocked discs of white and black. These two, naturally, yield grey when rotated, the grey becoming lighter or darker according as the white or black predominates. The aim is now to adjust the smaller discs to the same brightness as the larger discs. Once the black-white discs are there for comparison, a colour may appear still visible in the larger discs which had remained unnoticed before, even against the grey of the background, which is essential in all colour experiments. If such is the case, the outer discs will require readjusting, and a fresh measurement must be taken. In the final match no difference between the two discs should be perceptible. An equation can then be obtained giving the brightness equation for these two particular colours, viz. A° Yellow + B° Blue = C° Black + D° White.

Flicker.—In colour-mixing, the fusion of the discs of coloured or colourless paper, depends upon the rate of rotation of the colour wheel. When the wheel first begins to rotate, the stimuli are of insufficient frequency to produce fusion, and flicker is produced. It is possible to distinguish two kinds of flicker, a coarse glittering flicker which appears first and then passes into a finer tremulous flicker. Once complete fusion has been obtained, no further change is visible in the disc, no matter how long or how quickly rotated. Flicker may be due to the colour

[1] Scripture, *Thinking, Feeling, Doing*, p. 128.

element or to the brightness element, or the total flicker may be caused by both. Flicker due to colour, is always eliminated first. Flicker, therefore, depends upon the brightness of the colour or colourless sensation, and also on the illumination at the moment of rotation. The brighter a colour sensation is, or the more intense it or a colourless sensation is, the quicker must be the rotation before flicker is abolished. The precaution is therefore to be noted, that in all colour-mixing experiments, care must be taken not to pass any judgment on the

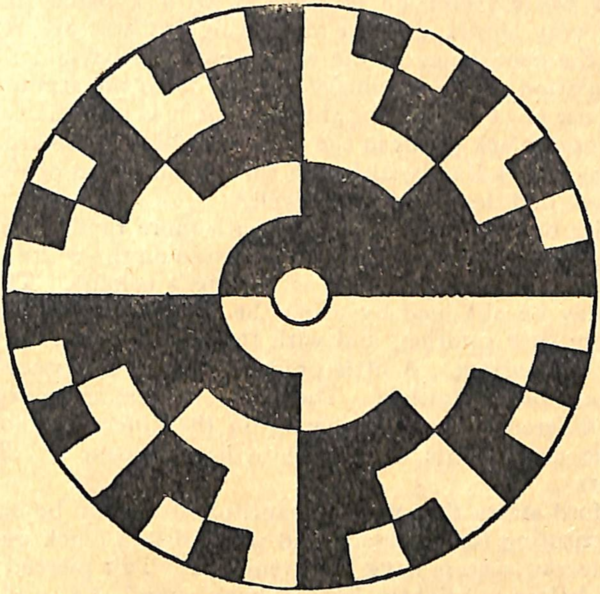


FIG. 3

rotating discs until flicker has been completely eliminated, in other words, until complete fusion takes place.

Talbot and Plateau investigated this phenomenon with great care. They carried out experiments to ascertain the relation between the brightnesses of the individual periodic stimuli and the brightness of the total fused sensation. Their results give us the Talbot-Plateau Law, which is to the effect that the total brightness after cessation of flicker is equal to the mean of the brightnesses of the individual stimuli. This is well

shown by the accompanying disc in the margin (Fig. 3). It matters not how black and white, for example, are arranged on a disc, the total effect in each case is a grey of the same brightness. On each of the five rings of the disc, the black and white are differently distributed, but on rotation each ring assumes a uniform grey. The brightness of each concentric ring is the same as it would be, had all the light been reflected uniformly over its surface. As the disc comes to rest, good flicker effects are visible.

If a white sector be interlocked with a black disc, and rotated very slowly, certain interesting features are revealed, due to the persistency of the white sensation beyond the time of stimulation. The "primary image" from the stimulus does not appear as of uniform brightness, but it is possible to see on it a series of black bands in the form of radii. These are known as Charpentier's Bands, although this phenomenon of recurrent vision was first described by Bidwell.[1]

Under bright illumination and with more rapid rotation of the same discs, various colours may be seen on the white surface. These are generally spoken of as Fechner's colours. The same effect may be obtained by using the Talbot-Plateau disc, but with very slow rotation, and with the eyes kept steadily fixed on any one portion. A little practice may be necessary before the colours become visible. These colours seem to be explained by the difference in retinal inertia for the different colours, so that the components of the white light appear at different moments.

Sanford states that very "beautiful effects can be obtained by substituting for the black and white disc a black one from which narrow sectors have been removed. This pierced disc is rotated before a brightly lighted background, e.g. a sheet of white cardboard in full sunlight, a bright cloud, or the clear sky."[2] The eye requires to be brought very close to the disc.

Twilight Vision.—So far we have been discussing the light-adapted or photopic eye, but when the dark-adapted or scotopic eye is considered, certain statements require modification. The eye is very readily dark-adapted temporarily. Whenever we pass from very bright light, such as sunlight, into a darkened room, we are at a loss until the eyes become used to the light, or

[1] Consult Bidwell, *Curiosities of Light and Sound*, London 1899. Also McDougall, *British Journal of Psychology*, 1, 78, 1904.

[2] *Experimental Psychology*, pp. 143-4.

speaking more technically, become dark-adapted. The converse, of course, also occurs when in passing from darkness into light we are dazzled at first, and require a little time before vision becomes normal. The vision has become dark-adapted, and requires to become light-adapted once more. Dark-adaptation, accordingly, is a relatively slow process, and is accompanied by an increase in the sensibility of the retina. Individuals differ in the rate and amount of adaptation, which accounts for the fact that some are able to see better than others in low illumination. The normal curve of sensibility shows a very slow accommodation during the first ten minutes, followed by a rapid increase during the next half-hour, but very gradual again after that, the increase being scarcely perceptible. It is interesting to note the fact, which Charpentier records, that dark-adaptation of one eye has no effect upon the other.

In photopic vision, the fovea is the region of greatest sensibility, but in the condition of dark-adaptation the fovea becomes the least sensitive part of the retina. In fact, the fovea of the retina may be regarded as night-blind. It is a well-known fact that in viewing the constellation of the Pleiades on a starry night with direct vision, only the brightest stars are visible. But if the eye is turned round a little to the side so that the stars are focussed upon the periphery of the eye, it is found that additional stars are seen. This clearly shows that the periphery of the eye is better adapted to night vision than the fovea. The cones so numerous in the fovea are connected with daylight vision, but for night vision we are dependent on the rods in the retina which the fovea does not contain. It is interesting in this connection to note, although the fact has been disputed, that nocturnal birds such as owls, have nothing but rods in their retinas. The blindness of the fovea—the centre of vision—is referred to as a condition of relative " central scotoma."

It is very rare for the eye to become completely dark-adapted in ordinary life or to become completely scotopic, for prolonged exclusion from light is necessary. But when such a state does result, certain interesting phenomena are observed. If a spectrum is shown to a dark-adapted eye and in a dimly-lighted room, it will appear colourless. The spectral band, nevertheless, will not be uniformly bright, but will show differences in brightness in the various parts. The red end of the spectrum will be darker than normal, the blue end brighter, and the brightest part of the spectrum will not be in the yellow, as in

the spectrum seen by the photopic eye, but in the green. This change in the position of the maximal brightness is called after the Austrian investigator who first discovered it, the " Purkinje phenomenon ". If the intensity of the spectrum is slightly increased, the colours gradually make their appearance in a definite order. If the experiment is reversed and the spectrum visible at first in all its hues, it will gradually become colourless with decrease in intensity, and the colours will be seen to disappear in a regular order. Abney, in his Tyndall lectures, aptly describes this: " At nightfall in the summer the order of disappearance of colour may often be seen; orange flowers may be plainly visible, yet, a red geranium may appear black as night; the green grass will be grey when the colour of the yellow flowers may yet be just visible. An early morning start in the autumn before daybreak will give an ample opportunity of satisfying oneself as to the order in which colours gradually reappear as daybreak approaches. Red flowers will be at the outset black, whilst other colours will be visible as grey. As more light comes from the sky the pale yellow and blue flowers will next be distinguished, though the grass may still be a nondescript grey. Then, as the light increases, every colour will burst out, if not in their full brilliance, yet into their own undoubted hue." [1]

Now, if a spectrum be viewed with the light-adapted eye in good illumination, and the intensity of light decreased, such phenomena will not take place. What happens is, that the colours merely become weaker and weaker, until they are too faint to give rise to any colour sensation and only black appears. But there is no change in the relative brightnesses. Evidently, therefore, Purkinje's phenomenon requires the condition of dark-adaptation as well as low intensity. Complete dark-adaptation rarely takes place, as pointed out above, and passing from a brightly lighted room into one of dark illumination is sufficient to produce the phenomenon; or merely reducing the intensity in the bright room elicits the result. Titchener states that, " if one goes straight from bright daylight into a perfectly dark room in which is exposed a spectrum of such low energy that no colour can be seen, then, as soon as one is able to observe at all, one observes that spectrum shows the Purkinje phenomenon." This leads him to state that, " twilight vision

[1] *Colour Vision*, p. 107

is primarily dependent, not upon dark-adaptation, but upon the reduction of the energy of light. What dark-adaptation does is to make the greys of twilight vision much clearer and stronger than they are without it." [1]

The Purkinje phenomenon does not take place in the region of the fovea, and as rods are absent there, these facts seem to suggest that the cones of the eye are connected with colour sensation under conditions of light-adaptation, whereas the rods are concerned in the production of colourless sensations when the eye is dark-adapted. Further, it has been discovered that the rods contain a certain substance known as visual purple which is highly sensitive to light. This substance is bleached most rapidly by green light, the point of maximal brightness in the dark-adapted eye, but red light, the darkest sensation in the dark-adapted eye, has no effect upon it. Further, visual purple is bleached far more rapidly than it is regenerated, a point in keeping with the observation that the process of dark-adaptation is a lengthy one, and the converse process of changing from dark to light-adaptation is much more rapid.

So far we have only considered the appearance of the spectrum in connection with dark or light adaptation of the eye. But adaptation, a characteristic of all the senses, is particularly important in the field of vision. We shall see, in the discussion of smell, that an odour experienced clearly on entering a room, soon ceases to be noticed. The organ of smell has become adapted to it. The same effect takes place in vision, either over the whole field, or over only part of it. In every case the same process is at work, the stimulus at first clearly discernible, gradually diminishes in intensity and ceases altogether. Adaptation resembles fatigue, but is more clearly advantageous to the organism. A familiar example will serve as illustration. On wearing a pair of green glasses every object at first appears green in colour, but after a remarkably short time adaptation sets in, and the green effect disappears. The same may take place with any bright colour which strikes our eye on its first appearance, but which soon loses effect as we grow accustomed to it. In colour, adaptation takes the form of tending to reduce all colour sensations towards colourless sensations, and all colourless sensations to medium grey. This is similar to saying that all colours on prolonged fixation tend to become mixed

[1] *Text-book of Psychology*, p. 80.

with their complementary colours and so grey is produced, and that all colourless sensations tend to become mixed with their complementary sensations, blacks with whites, and whites with blacks, until a medium grey is formed.

Contrast

Successive Contrast.—Let us turn now to the after-effects of adaptation, where we shall see at work very clearly the effect of complementary colours. If we take again our example of wearing green spectacles, then we shall find, once they are removed from our eye, that everything appears of a reddish tinge. Had they been blue in colour, objects would have seemed yellowish in tinge. The removal of the stimulus, no matter of what colour it may be, is followed by the appearance of its complementary colour. Such phenomena are described as contrast phenomena, and they take place frequently; generally, however, they pass unnoticed. Under experimental conditions they can be easily demonstrated. If a patch of colour be steadily looked at for 15 or 20 seconds and then the eyes fixated on a larger colourless background, preferably of grey, a patch of colour identical in shape but complementary in colour and surrounded by a bright halo, will be observed. This is described as successive contrast, and what has been obtained is a negative after-sensation—sometimes loosely called a negative after-image. The original patch of colour and the after-sensation bear the same relationships of light and shade which the photograph does to the negative. The after-image can also be obtained by merely closing the eyes after the fixation of the stimulus. If the after-image is projected on a coloured background, it fuses with that colour. Red, projected on grey, yields a green after-image, whereas red projected on yellow produces an after-image greenish-yellow in hue. Red projected on a red background tends towards grey, for the green of the after-image is neutralized by the red of the background; red projected on a green background produces a highly saturated green of great brilliance and purity. The brightness of the after-image also varies with the brightness of the background. The colour of the halo tends to be of the same hue as the stimulus if the fixation is not too long nor the stimulus too bright. But, as the fixation becomes longer the brighter becomes the colour of the halo, until it may ultimately become white, or even tinged with the complemen-

tary colour. Generally, the colour of the halo tends to be complementary to the colour of the after-image.

White and black behave in the same way as colours. White gives on a grey background, an after-image of intense black, whereas black produces an after-image of dazzling white.

For the production of after-images, concentration and attention are essential, for they are easily abolished. It is advisable to put a tiny pencil mark in the centre of the colour to be fixated, or a pin-prick may be sufficient in order to produce steady fixation. The least movement of the eyes or wandering of the attention may inhibit the after-sensation ; it is for these reasons that they are so seldom observed outside of the laboratory.

The after-image may or may not appear immediately after the original colour has ceased stimulating the retina. The time of appearance depends upon various factors, such as the time of stimulation, the difference, if any, in the brightness of the background, and further, the size of the area of the colour fixated.

There is still one further characteristic of the after-image to be observed, namely, its periodicity, which was first described by Plateau. The after-image does not remain as a continuous sensation, but comes and goes at intervals. The number of fluctuations may be as many as twenty or even thirty. These have been attributed to the unconscious movements of the eyes. Others refuse to accept this explanation, and hold that the periodicity of after-images is an inherent characteristic of all after-sensations and a fundamental law. The total duration of the after-image is not constant, but varies with such factors as have already been enumerated, such as the size and time of fixation of the original stimulus.

With a little more care, a positive after-sensation may be obtained. If the eyes are covered with the hand, and then uncovered so that a bright light is momentarily fixated, on closing the eyes or covering them again, the sensation will be seen as an after-image, but positive in character. That is, it appears in its original brightness. If the original sensation is coloured, the positive after-image will appear of similar hue. This is known as the " homochromatic " after-image.

The positive after-image may be obtained in the same way as the negative after-image. A colour may be looked at momentarily (bright illumination gives the best results) and then the

eye closed, or a colourless surface fixated. The after-sensation will appear not only of the same shape but also of the same hue. The same sensation is experienced when a candle flame is extinguished, but the flame still seems visible. The majority of individuals have experienced a positive after-sensation from looking at intense stimuli, such as a dazzling light.

Positive and negative after-images, although apparently antagonistic, seem to be closely related, and frequently during the fluctuations described above, positive and negative after-images appear alternately. A positive after-image may pass into a negative after-image.

Before a positive after-image (either coloured or colourless) disappears, it often passes through a series of colours. This "flight" of colours has been well described by Helmholtz. He states that after our eyes have been stimulated momentarily by white light the after-image "passes rapidly through greenish-blue into beautiful indigo-blue, later into violet or rose-red. These colours are bright and clear. Then follows a dirty or grey orange, during which the positive after-image generally changes to a negative after-image, and in the negative image this orange often becomes a dirty yellow-green."[1] Differences occur in this series according to the intensity of the stimulus.

This phenomenon has been more recently investigated by McDougall.[2] He found that three colours constantly recurred in regular order after stimulation with white light. These are green, red, blue, green, red, blue, etc., the starting-point varying with the intensity of the white light. For example, moderate intensity causes red to appear first, followed by green, but brighter light gives green first, then red, then blue, then green again. "The red is a rich crimson red, decidedly less orange than the red of the solar spectrum, the blue is a rich ultramarine, and the green, a pure green, having no inclination towards blue or yellow."[3] Fading phases are also characteristic of after-images derived from colour stimuli.

Simultaneous Contrast.—So far we have been discussing successive contrast, where the contrast effect has occurred after the stimulus has been withdrawn. But contrast may take place simultaneously while the stimulus is still present. Each area which stimulates the retina is modified by the surrounding areas.

If a yellow patch of colour be placed against a colourless

[1] *Handbuch der Physiologischen Optik,* 3rd Edition, ii., p. 208.
[2] *Mind,* x. N.S 235, 1901. [3] *loc. cit.*

background, it will be observed that round the edge of the yellow the background will assume a bluish tinge. This contrast effect is enhanced if the whole is covered with tissue paper, for this serves to make the colour edge less defined and strengthens in consequence the contrast effect. In fact, the contrast often disappears when the tissue paper is removed, because the strong edges of the coloured patch cause the contrast to be subjectively destroyed. In the same way, a colourless patch, black, white, or grey, placed on a coloured square, assumes the complementary of its background. A grey patch on a red square acquires a greenish tinge, a grey patch on a green square acquires a reddish tinge. On every occasion, the colourless patch will assume the complementary colour of the coloured patch. It is this phenomenon which is spoken of as simultaneous contrast. The colour which causes the change in the colourless patch is the *inducing* colour; the colour which the colourless patch assumes is the *induced* colour. On prolonged fixation these contrast effects disappear, and the stimulus colour *induces* its own colour on the colourless surface. This is known as simultaneous induction.

Contrast effects are strongest when the two surfaces are of equal brightness. This can be easily demonstrated. If a strip of green paper be placed on a black background, and a strip similar in brightness and hue be placed on a white background, the difference which the two backgrounds make becomes clearly visible. The green on a black background appears deeper and more saturated; the green on the white background, however, appears paler and lighter. The colour fields change in brightness according to the fundamental law of opposites—a dark background makes a neighbouring colour brighter, a light background makes it darker. The same law holds with a colourless surface on a colourless background. A grey patch looks brighter or darker according as its background is black or white. Such effects are said to be conditioned by brightness contrast.

The contrasting surfaces do not require to be one on top of the other to produce contrast effects, but it is sufficient that they are adjacent. The nearer the fields are to one another, the greater is the contrast, and on gradually increasing the space between them, a corresponding diminution of contrast will be observed. The contrast effect is not uniform throughout, but is strongest round the edges where the two surfaces adjoin. This has been called *marginal* contrast (*Randkontrast*) and has

been distinguished from the contrast effect on the remainder of the area which has been termed *surface* contrast (*Flächen-kontrast*). The size of the areas used also affects the contrast. A small strip of white paper and a large square of white paper placed apart upon a similar background do not appear identical, for the smaller area is more conducive to stronger contrast effect than the larger area.

Beautiful contrast effects may be obtained with coloured shadows, a method which dates from the time of Goethe. Arrange two lights so that they shall cast a double image of a small object—such as a pencil—on a white screen. Ordinary daylight may be used as one source, provided the light be not too strong, for, unless the sky is overcast, the light from it will be blue. By the introduction of coloured glasses in front of one of the lights, beautiful coloured effects can be produced, and the shadow of the pencil caused by that light will appear each time of a complementary colour. Or the following method may be used : Arrange a lantern so as to illumine a white screen, and introduce a coloured glass in the carrier. A second source of light may be supplied by an electric lamp. Arrange this in front of the lantern—but to the side, so that its rays are not interfering with those of the lantern, although its light also illumines the white screen. The white screen is being lighted, then, from two sources. If a pencil is interposed between the lantern and the coloured screen, the red rays are cut off, and the area of the pencil is illuminated solely by the white light from the lamp, and will assume the complementary colour of its surroundings. By the introduction of differently coloured glasses other contrast effects can be procured.

The Halo, or *Lichthof* (of Hering), which appears with long fixation around coloured or colourless surfaces is also an effect of simultaneous contrast.

There is one point in reference to all cases of contrast, whether of brightness or of colour, which must not be overlooked, and that is, that all contrast is reciprocal. It is not only the one surface which is affected, but both contrasting surfaces are influenced. It can be shown under experimental conditions that what one gains in brightness, for example, the other loses. All over nature this contrast effect is at work, although it is seldom noticed. Each colour tinges its surroundings with its complementary colour and the effect is stronger in nature than it is in the laboratory, although we inhibit it unwittingly. But in nature we often refuse to see such subjective

colours and, unless we possess the artist's eye, are apt to depend too much upon our "memory colour" of objects. One familiar example is that of the rosy glow of the sunset, which, falling on the snow of the hills, gives it a red tint through which we presently see the snow as white.

"It is clear from all these facts, that the lights and colours of the field of vision at any given moment are not exclusively determined by the physical stimuli, the reflected light waves, which affect the eye. What we see depends, in part, upon contrast; in part, also, upon the preceding adaptation of the eye, general and local. It is clear, further, that contrast and adaptation are in one sense opposed, but, in another sense, mutually supplementary principles. Contrast is present throughout the field of vision as soon as we open our eyes; adaptation requires time. Contrast is a differentiating, adaptation a levelling principle. Hence contrast helps us to discriminate all the separate objects by which we are surrounded, while adaptation prevents our being fatigued or disturbed by their variety after this discrimination has taken place."[1]

Field of Vision

We have seen in the preceding sections the many ways in which colours vary, and the different effects which one colour may have upon another. Yet to all these curious phenomena another must be added. Colours may appear differently when looked at by different parts of the retina. When we regard an object directly, its image is thrown on the fovea of the eye, which is the centre of acutest vision. Other objects in the environment stimulate the surrounding area. The total area perceived by the retina constitutes the field of vision "which is, therefore, the projection outwards of all the points upon the retina which can initiate visual sensations."[2] The objective field of vision extends vertically about 100°, horizontally about 145°.[3] In foveal vision, all colours and brightnesses are visible, but with the extreme edge, or with the periphery of the eye, only greys or brightnesses are experienced. The field for brightness is accordingly much larger than that for colours, while blue and yellow have a larger field than red and green. Thus, in the retina, three zones can be distinguished, although they cannot be rigidly separated. The

[1] Titchener, *Text-book of Psychology*, p. 78.
[2] Parsons, *Colour Vision*, p. 72. [3] Abney, *ibid.*, p. 10.

inner zone is the area of complete colour and colourless sensation, the middle zone is colour-blind to reds and greens, although blues and yellows are seen; in the outer zone, total colour-blindness occurs and only brightness can be experienced.

The field of vision is usually mapped out by means of a perimeter, but the following method may be used. The observer is seated before a blackboard on which are drawn a

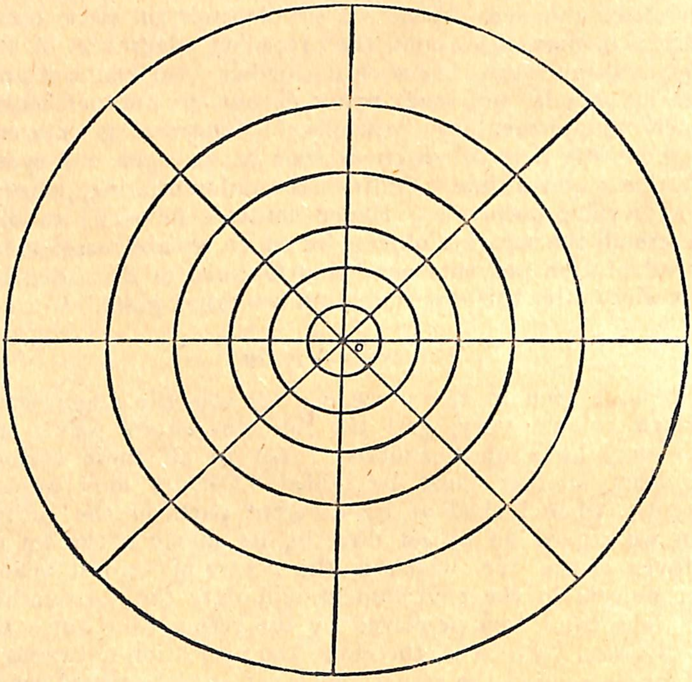


Fig. 4.

series of concentric circles. The eye of the subject is on a level with the centre of the circles and directly fixates it. A chin rest is necessary to keep the head in a steady position. The circles are so drawn that they represent the tangents of the angles at the eye of 10°, 20°, 30°, 40°, 50°, 60°, etc. (Fig. 4.).[1]

[1] Look up a table of Natural Tangents in a Book of Logarithms and multiply them by the distance of blackboard from the eye. The products give the radii of the circles.

A metal rod with bifurcated end, or some similar contrivance, is necessary to hold the various pieces of coloured paper. When the subject is ready, that is, with left eye closed, and right eye fixated on centre—for we only investigate the field of vision for one eye at a time—the experimenter inserts a piece of white paper (2 cms. × 1 cm.) into the holder and places it at the point marked A on the diagram. The paper is moved very slowly and continuously along the line A O until it appears visible to the subject. Note the place in degrees. Repeat on the other radial lines in a similar fashion, then by joining on each line the first place of appearance of white, the field of vision for white is mapped out. With coloured papers the procedure is exactly similar, but more than one observation may be necessary, and frequent pauses must be instituted to avoid fatigue. The one essential is, that the subject must try to keep the eye steady on the centre and not follow the moving paper, which, unconsciously, he is apt to do. As one proceeds from the circumference of the circle inwards, colour changes will be observed. When the different zones are passed through, red, for example, will first be seen as a grey, then as it passes through the middle zone, it will appear as yellow. Later, it will develop into an orange, and finally will appear in its true hue. It is advisable to locate where these changes occur. The following examples are taken from Baird's Monograph on this subject:—[1]

Red first appears yellowish, then yellow, then orange-yellow, then yellow-orange, orange-red, and finally red.

Reddish-Orange appears yellowish, orange-yellow, then reddish-orange.

Yellow appears yellowish, and gradually increases in saturation.

Green appears yellowish, yellow, greenish-yellow, and green.

Blue appears blue, and gradually becomes more saturated.

Violet appears bluish, then blue, and finally violet.

Purple (red end) appears yellowish, then orange-yellow, yellow-orange, orange-red, red, purplish-red, reddish-purple, and finally, its own colour tone of purple.

All colours appear, of course, as grey first of all. Then reds, oranges, blues, and greens, are seen as yellows, while blues and violets are seen as blue. Finally, the correct colour tone is visible.

[1] *The Colour Sensitivity of the Peripheral Retina.* Publication 29 Carnegie Institution.

Once the experiment is completed, the field of vision for each colour can be mapped out. Blue and yellow have an area about 10° smaller than that for white, while red and green have an area about 20° smaller. The results vary considerably with the size of coloured paper used and the saturation. If the papers are of sufficient area and intensity they may be visible right out at the periphery. All that can be said is that these zones are of relative—not absolute—colour sensitivity.

The field for shape can also be determined by this same procedure, by altering the shapes of the coloured paper, moving them from periphery to centre until the correct shape in each case is clearly discerned. The area for shape is a relatively limited one.

Direct vision accordingly is concerned with colour and shape, while indirect vision or peripheral vision is, in the main, concerned with light and movement. As Seashore points out, this arrangement is a biological one. The functions of indirect vision "are those of a scout or guardian. The life-preserving value of this arrangement is clear. Consciousness is warned of the presence or approach of an object beneficent or noxious to life, by impressions of luminosity or movement in the indirect field. If then the signal is heeded, the eye quickly turns so as to bring the object of scrutiny into the direct field where its true nature can be seen accurately, by the most efficient and economical expenditure of energy."[1]

We do not notice that the peripheries of our eyes are colour-blind until we test them under experimental conditions. In the same way, we are never made aware of the fact that a certain part of the retina—where the optic nerve enters the eye-ball—is totally blind. Consequently, any object which is focussed on the blind spot—as it is termed—is invisible. If the cross on the left be fixated with the right eye—the left eye

× ●

remaining closed, and the book held about 7 or 8 inches from the eye—the presence of the blind spot will be demonstrated. Move the book slowly backwards and forwards, and at a certain point the dot on the right will disappear. By holding the page upside down, the left eye may be tested in exactly the same manner.

To definitely locate the blind spot, the same arrangement

[1] *Elementary Experiments in Psychology*, p. 38.

of circles used in plotting the field of vision may be employed. When the white piece of paper travels along the central horizontal radius (A O) there will come a point at which the white paper will disappear. The first point of disappearance marks the one limit of the blind spot. Then start from the centre and slowly move paper out towards the periphery. The observer will again record its disappearance. This marks the other limit of the blind spot. These limits should range somewhere about 15° to 18°. By a little modification of the method the complete area of the blind spot (which is elliptical in shape) may be determined.

The reason that we are not conscious of the existence of a blind spot, or rather, of two blind spots—one in each eye—is because we are continually filling in the blind spot subjectively on the basis of the surrounding areas. Further, when the two eyes are working in co-operation, their fields of vision overlap.

Colour Blindness.—The condition of the periphery of the eye, namely, one of colour blindness, is found in all normal eyes. But with certain individuals, colour blindness does not occur only in the periphery but extends over a larger area of the retina.

The earliest case of colour-blindness on record seems to be that of Harris, reported in 1777. He remembered that when young, other children could discern cherries on a tree by some "pretended" difference of colour, though he could only distinguish them from the leaves by their difference of size and shape. Twenty years later, Dalton's description of his own case appeared, and attracted considerable attention. Dalton states that while he found that most people could distinguish six colours in the solar spectrum, his colour sensations were reduced to two, blue and yellow, or at the most, three—blue, yellow, and purple. Dalton discovered his defect by the merest accident. A flower which appeared blue to him by daylight, changed its hue by candle-light, and presented a full pink. Dalton was amazed at this change, but was more amazed when on asking some friends to observe the phenomenon he found that the colours remained unaltered to them, and that the flower which was blue by daylight, remained blue in artificial light. This description by Dalton was the beginning of a systematic study of colour-blindness.

The defect has been found to take three different forms, red-green blindness, blue-yellow blindness, and total colour-blindness.

4

1. *Red-green Colour-Blindness.*—The study of red-green colour-blindness is very important for two reasons, first, because of the frequency with which it occurs, and second, because of the colours which are confused. From its name it will be gathered that red and green are the two difficult colours for such colour-blinds. When it is recalled that red and green are used extensively for signalling purposes, both on the railway and at sea, it will be evident that the presence of this form of colour-blindness cannot be overlooked.

This type of partial colour-blindness is not rare by any means. It occurs in the male population in the percentage of 3·5 or 4, whereas among the female population the percentage is ·088, or about one in every thousand. The unfortunate fact about colour-blindness is that it is hereditary. Usually it is transmitted directly in the male line, although any generation may be free from the colour anomaly. It tends, also, to pass over the female descendants but to reappear in the males of the next generation.

Colour-blindness, therefore, is congenital, and cannot be cured. Remedies have been repeatedly tried, but ultimately have been discarded as useless. It is not a disease, but merely a physiological condition. Colour-blindness must not be confused with colour-ignorance; the latter, of course, can be easily cured and is merely a matter of learning the names of the colours and associating them properly.

In normal vision the spectrum is seen to contain six colours, or even seven, but if we test a red-green colour-blind with the spectrum we find his colour vision reduced to two colour sensations—blue and yellow. What does he see in place of the other colours? Colour-blinds are not quite uniform in this respect. With some, yellow and blue may replace all the other colours. Red, orange, yellow, and green, may be seen as different shades of yellow, blue and violet as shades of blue. The red will be a very dark yellow, in fact will appear almost black with just a tinge of yellow in it, the orange will not be quite so dark a yellow; the yellow will be brighter still, and so on. It will be evident that under such circumstances an individual may be quite unaware of his defect and others may be unaware of its existence also. By convention he has learned that what he sees as a black with a tinge of yellow is called red by other people, and he naturally associates this particular shade of yellow with the name red. It is not surprising that the colour-blind thinks

other people are seeing colours exactly the same as he does. Dr. Pole, who has advanced the knowledge of the subject extensively, remained unaware of his defect for 30 years. Further, it is possible in daily life for a colour-blind who is unaware of his abnormality to hide his defect, and he can very often do so with surprising skill. It is not until his colour vision is tested by scientific methods that his lack of ability to differentiate colours is revealed.

All colour-blinds do not have their invisible colours replaced by yellow and blue. Consider, for example, one of the cases studied in the George Combe Psychological Laboratory at Edinburgh,[1] which revealed a spectrum as follows: Red was seen as black, orange as dark grey, yellow was discriminated, green and blue-green were seen as grey, blue could be distinguished, but violet appeared a dark grey. Only two narrow patches of colour were visible in the spectrum of this colour-blind—a narrow patch of yellow, and a narrow patch of blue. All other colours gave sensations of grey; this, however, is an extreme case of red-green colour-blindness.

When a grey replaces a colour in the spectrum, it is said to form a neutral band. Very often the green appears as grey, but sometimes the neutral band in the centre of the spectrum is limited to the blue-green. This band seems to extend according to the severity of the colour defect. A second neutral band appears beyond the spectrum—in the extra-spectral colours—in fact, occurs in the complementary colour of the green forming the spectral neutral band.

Two important and distinct classes of red-green defect must be distinguished. In the one case, the spectrum appears of the same length as in normal vision, but in the other the end of the spectrum is cut off, and red, if it is the red end, violet if it is the violet end, appears black. Usually, the shortening takes place at the red end, although cases of shortening of the violet end have been recorded. These cases were named by V. Kries *deuteranopes* and *protanopes* respectively. As deuteranopes are classified those who can only experience the colour sensations blue and yellow, but whose spectrum is of normal length. As protanopes, on the other hand, are designated, those whose colour systems again consist of blue and yellow, but who, in addition, have the spectrum shortened or cut off at the red end. Yellow forms the maximal point of brightness in the case of the

[1] *Vide* Collins, *Colour Blindness.*

former, but green in the case of the latter. The two terms *photerythrous* and *scoterythrous* have been suggested by Rivers to describe these two classes.

All cases, however, are not so extreme, and the general finding, which is gradually gaining ground, is that there are different degrees of colour-blindness—extending from extreme cases in which blue and yellow are the only two colours visible, to milder cases in which the blindness to red and green is not complete. Some cases are typical red-green colour-blinds, but seem able occasionally to distinguish red and green if they are bright enough or vivid enough. If such is the case, no rigid classification of colour-blinds can be made, for numerous transitional cases will appear between normality and complete red-green blindness.

2. *Blue-yellow Blindness.*—Congenital blue-yellow blindness has not been definitely established, only three seemingly authentic cases having been recorded. The defect is generally thought to be acquired and to accompany pathological changes in the retina. The confusion colours of this form of colour-blindness are, as its name suggests, yellow and blue. In the case described by Richardson blue was seen as a dazzling white. V. Kries terms this form of colour-blindness *tritanopia.*

3. *Total Colour-blindness.*—About eighty cases in all have been reported of total colour-blindness or of monochromatic vision as it is called. Although, therefore, it occurs much more rarely than red-green colour-blindness, its existence is beyond dispute.

The spectrum of the totally colour-blind resembles a colourless band whose parts only differ in luminosity, for monochromats are unable to experience any colour sensation whatever. Their world appears to them as an engraving appears to us. In many cases, the blindness to colours is accompanied by some abnormality of vision such as photophobia or nystagmus and poor central vision may also be present.

As in red-green blindness, two distinct types can be distinguished, so we find in total colour-blindness a similar distinction drawn. In the one form, the point of maximal brightness lies in the region of the yellow, while in the other form it lies in the region of the green, a condition similar to that found in the dark-adapted eye. In a number of cases, the *achromatopia,* as it has been termed, has been found to be accompanied by an " absolute central scotoma." This means that the fovea—the

point of central vision—is not only blind to colour but can experience no light sensations of any kind. It is totally blind, although beyond the fovea vision may be practically normal.

Acquired Colour-blindness.—Where cases of acquired colour-blindness are met with, they are generally found to be of a temporary nature. A very common pre-disposing cause lies in over-indulgence in tobacco. If such is the cause, or if the abnormality can be traced to a drug such as santonin, the defect is progressive in nature. To begin with, a failing in the visual faculties may be the only effect, and generally its more advanced stages have developed before it becomes noticeable. In most cases, however, absence of the cause is sufficient to bring the colour-vision back to normal.

In some forms of acquired dichromatism, the fovea only is impaired. It alone becomes colour-blind, leaving the rest of the retina unimpaired as regards colour sensation. This fact becomes significant when testing for practical purposes. It is evident that the colours used in testing should not be too large in area, otherwise they will stimulate not only the diseased fovea, but the unimpaired parts surrounding it, in consequence giving results compatible with normal colour vision. Further, it would seem advisable that tests, for practical purposes, should be instituted regularly, especially so when we find that the two colours generally affected are the important ones of red and green.

Colour Weakness.—Certain individuals, although not colour-blind, are unequally sensitive to red and green. They are said to have "weak" or "anomalous" colour vision. These were first observed by Seebeck in 1837, but it was not until Rayleigh reported his experiments in 1881 that these cases were understood. In equating red and green equal to yellow (the Rayleigh equation) some were found to require far more red than the normal, others required an excess of green. V. Kries has applied the name "anomalous trichromates" to them which has been generally accepted. Anomalous trichromates are generally divided into two groups corresponding to the two groups of dichromates, deuteranomalous trichromates, whose sensitiveness to green is below normal, and protanomalous trichromates, whose sensitiveness to red is below normal. Such cases are characterized by greater susceptibility to contrast than normal individuals, and require colours to be nearer to them than is ordinary before they can recognize them.

Tests for Colour-blindness.—In devising a test for colour-blindness, certain principles have to be kept in mind. Certain colours are "confusion" colours, and are regularly a source of difficulty to the colour-blind. Others are correctly seen and offer little trouble. The test must make use of the colours which are most often confused. Then any secondary means of recognizing colours must be dispensed with, and the subject must be made to rely solely on his colour sensation. Guessing can easily be detected under rigid experimental conditions. Further, if the tests are for practical purposes, it is essential that they do not take too long to administer, and they must be of such a nature that examinees cannot be coached to pass them. Below are given samples of some of the tests devised.

(*a*) *A Spectral Analysis*, by means of a spectrometer, is one of the most frequent methods employed.

(*b*) *Stilling's Pseudo-Isochromatic Tables.*—These tables, fourteen in all, consist of coloured numbers on coloured backgrounds. They are based on the fact that if two colours of equal brightness be on the same side of the neutral band of the spectrum, they cannot be distinguished by the colour-blind, because they do not present any contrast. The tables test red-green blindness and blue-yellow blindness, and also pick out cases of normal length of spectrum from those of shortened spectrum.

(*c*) *Holmgren's Wool Test.*—The wool test is based on comparison of different colours. Many advantages have been claimed for it, such as portability and simplicity, and the fact that the wools reflect the light equally in every direction.

The test consists of over 100 skeins of wool of various colours, including tints and shades. These "confusion" skeins are spread out in good daylight illumination before the examinee. Thereupon he is handed a "test" skein, its name not being mentioned, and is asked to pick out from the skeins before him all those of a similar hue, irrespective of shade. Holmgren employed three test skeins, a very pale green to verify the presence of the defect, a light purple or pink to decide if the defect be one of red-blindness or green-blindness, and a full-red skein to act as a confirmatory skein. The choice of such skeins was based on the theory of which Holmgren was an advocate—that of Young-Helmholtz—but the test skeins have undergone many modifications since then and different colours have been suggested from time to time by different investigators.

(*d*) *Colour Equations.*—These are more for theoretical than for practical purposes, because full reliance is placed on the

subject, and there is no objective control. A disc of green may be matched with interlocked discs of black and white, or with one of red; or a red disc may be matched with interlocked discs of red and yellow. The Rayleigh equation may also be tried.

(*e*) All *contrast* experiments may be used—such as after-images and shadow contrasts.

(*f*) *Nagel Card Test.*—There are two sets of cards, 16 marked A and 4 marked B. In section A, the 16 cards are spread out in good daylight illumination. The subject stands before the table on which the cards lie, and is asked to indicate his answers by pointing to the cards he selects. Each card contains a circle of variously coloured dots. Four questions are asked: (1) On which cards are there red or reddish spots? (This does not preclude other colours being present.) (2) On which cards are there red spots only? (3) On which cards are there green spots only? (4) On which cards are there grey spots only? In section B the colour-blind is asked to designate each colour he sees on the cards.

(*g*) *The Edridge-Green Lantern.*—This lantern was devised to detect all dangerous colour-blinds. It consists of five discs, three containing seven coloured glasses, one containing seven modifying glasses, and one containing six different-sized apertures. The size of the aperture may be varied and is intended to correspond to the distance of the examinee from a railway signal lamp, or a ship's lamp. The coloured discs are clear, red A and B, yellow, green, signal-green, blue, and purple. The three discs are similar in every respect. The colours are brought into view by moving one or more of the handles into position until they correspond with the scale at the top of the lantern. Disc No. 5 contains the modifying glasses which, when placed before any coloured light modify the light so that it appears as it would under certain atmospheric conditions. The five neutral glasses represent fog, the ground glass, mist, and the ribbed glass, rain. The normal-visioned can still distinguish the colours, except with the thickest neutral. But the colour-blind find the task a very difficult one. The examinee is shown the coloured lights with and without the modifying glasses, and in each case is asked to name the colours. Various combinations of colours may also be shown. This test is very reliable for detecting colour-blindness.[1]

[1] A *Group Test for Colour Blindness* intended for use in schools has been devised by Drever and Collins.

Colour Theories

We have been dealing with some of the wonderful complexities of our colour vision, and the question now arises: is there any explanation which will enable us to understand what takes place in the retina to cause all these phenomena we have been describing? Theories of colour vision have been propounded with this end in view, and the most important of these we shall now consider.

The Young-Helmholtz Theory.—The Young-Helmholtz Theory, first propounded in 1801 by Thomas Young, was resuscitated in 1860 by Helmholtz. It is based on three elementary colours, carmine red (a red, bluer than the extreme red of the spectrum), yellowish-green, and ultramarine blue, which are sufficient to produce all colour and colourless sensations Corresponding to these are three nerve fibres in the retina, each responsive maximally to one wave-length. In other words, the action of the long wave end of the spectrum affects the first, of the middle wave-length the second, and of the short wave-end the third, but light of all kinds excites all three fibres, though in varying degrees. In the more modern statement of the theory these three nerve fibres are replaced by three photochemical substances. When all three substances are stimulated, the achromatic sensation prevails; when they are stimulated in varying proportions, all the colours of the spectrum are produced. In the absence of any stimulation we experience the sensation of black.

Every colour theory must explain the principal colour phenomena, and on its ability to do so must its validity be based.

Colour-mixing seems to be adequately accounted for by this admixture of three primary colours. The explanation of contrast is open to serious criticism. Positive after-images are said to be due to retinal inertia, once the "red" substance is stimulated, it cannot cease immediately the stimulus is removed. Negative after-images are explained by retinal fatigue. The red substance, for example, becomes fatigued, and the rays stimulate more powerfully the remaining two substances, and in particular, the green apparatus. This conception of the role played by fatigue is open to objection, for after-sensations can be obtained with such short fixation that fatigue cannot possibly have been produced. Further, it has been shown that lights of greater wave-length than 550 $\mu\mu$ do not act upon the violet

component. Yet the saturation of yellow (589 $\mu\mu$) is undoubtedly increased by previous stimulation with the complementary blue.[1] The explanation of simultaneous contrast is a very artificial one. Helmholtz reduces all simultaneous contrast to a purely subjective basis. The reason why a patch of grey placed on a green background becomes tinged with red, is that we, imagining that part of the green is transparent, through it see the grey. From past experience we know that before we can see grey through green as grey, it must be tinged red. In simultaneous contrast we apply this previous knowledge unconsciously. But it seems that past experience tends rather to inhibit the contrast than accentuate it. Total colour-blindness is accounted for by the absence of all three photo-chemical substances; partial colour-blindness by the absence of one of the substances. The absence of the red element causes an inability to see reds, and accounts for the red-blind (or protanopes); lack of the green element a corresponding inability to see green, the green-blind (deuteranopes); while, if the third element is missing the condition of the blue-blind (tritanopes) occurs. For a time the facts of colour-blindness seemed strongly in favour of this explanation. But soon, doubts began to arise as it was frequently confirmed that the sensations of the colour-blind were those of blue and yellow. Dr. Pole, himself a colour-blind, vigorously upholds this assertion, and amassed extensive evidence to support his claim, chief of which was the case studied by v. Hippel, which was reported in 1880. This was the first case of monocular colour vision observed, and the colours seen by the colour-blind eye, and verified by the normal eye, were blue and yellow. Further, the division of colour-blinds into red-blind and green-blind, is an unnatural division, and the theory does not seem to account satisfactorily for the milder cases of colour-blindness in which total blindness to red and green does not exist. Finally, if colour blindness is a reduction system, and due to absence of one of the elements it is difficult to reconcile the theory with the fact that the white sensations of the colour-blind are the same as those of the normal eye.

The theory cannot account for colour-blindness, nor for contrast, nor can it give any explanation of peripheral vision. Finally, the fact that colour stimuli may evoke colourless sensations under conditions of low intensity cannot be adequately explained. Its defect, therefore, seems to lie in the absence of

[1] Parsons. *Ibid.* p. 231.

some mechanism to explain achromatic vision. Various modifications of the Young-Helmholtz theory have been propounded merely with this aim in view. McDougall, for example, accepts the three fundamental colours, red, green, and blue of Helmholtz, but adds an independent mechanism for white, having its retinal seat in the rods. In other words, he adopts the duplicity theory of v. Kries, which is to the effect that achromatic scotopic vision is a function of the rods, while the cones are concerned only with photopic vision. He also gives a more satisfactory explanation of successive and simultaneous contrast. The sensation black is experienced when "complete fading" occurs, and the visual cortex is at rest. Colour-blindness and peripheral vision are both explained as following his theory of the evolution of the colour sense. (See *Mind*, N.S., vol. x., 1901.)

The Hering Theory.—The theory of Hering is based on six "elementary" colours, red, green, yellow, blue, white, and black. These can be arranged in pairs, red and green forming one pair, blue and yellow a second pair, while white and black form a third pair. The components of each pair are complementary to one another, and are at the same time opposed and antagonistic. Corresponding to these two colour pairs, there exist two elementary systems, one of which produces the sensations of red and green, the other yellow and blue. A third system causes the colourless sensations of black and white. Each of the substances can undergo a building up, or an anabolic process, and a breaking down, or a katabolic process.

Red	is caused by —	katabolism	in the	red-green	apparatus
Orange	,, ,,	katabolism	,,	red-green	,,
		katabolism	,,	yellow-blue	,,
Yellow	,, ,,	katabolism	,,	yellow-blue	,,
Green	,, ,,	anabolism	,,	red-green	,,
Blue	,, ,,	anabolism	,,	yellow-blue	,,
Violet	,, ,,	katabolism	,,	red-green	,,
		anabolism	,,	yellow-blue	,,
White	,, ,,	katabolism	,,	white-black	,,
Black	,, ,,	anabolism	,,	white-black	,,

In most kinds of stimulation all three systems are set in action in different proportions, although light which works on the red-green has no influence on the blue-yellow, and vice versa. Black, according to Hering, is a sensation: the intrinsic light of the retina (i.e. what is experienced when the retina has

been for a short time devoid of any stimulation which, by some, is termed the sensation of black) a " mean grey." Brightness of colour sensations is due partly to their own "specific brightness," partly to the action of the black-white apparatus. The warm colours, red and yellow, possess an inherent brightness: the cold colours, green and blue, possess an inherent darkness.

Colour-mixing is explained in a manner similar to that of Helmholtz, as due to the action of light on the colour apparatus of the retina. Complementary colour-mixing is due to the action of light on the two antagonistic processes, say blue and yellow which cancel one another and produce grey. The black-white apparatus is also excited. This leads to one criticism which has been levelled at Hering's theory. Blue and yellow, or red and green in a state of equilibrium, cancel one another, but black and white fuse and produce all varieties of grey.

Positive after-images are ascribed to exhaustion of assimilation during fixation, so that all that remains is a feeble process of dissimilation. This has been negatived by the observation that a positive after-image passes into a negative one, if the background on which it is fixated is brighter than that of the after-image. Negative after-images are caused by the tendency of the visual apparatus to maintain equilibrium. If the blue process is stimulated, the yellow is also stimulated before equilibrium has been regained. Simultaneous contrast receives here a physiological explanation as distinct from Helmholtz's strained psychological one. An activity in one part of the retina arouses an activity in the antagonistic process, which extends to contiguous areas.

Colour-blindness is caused by the absence of one or more of the visual systems of the retina. Lack of the red-green substance causes red-green blindness, lack of the blue-yellow substance causes blue-yellow blindness, while absence of both systems produces total colour-blindness. The peripheral zone of the retina shows the same conditions as in colour-blindness, for only the white-black substance is present. Red-green blindness corresponds to the middle zone of the retina, where yellow and blue are the only colours experienced.

Hering's theory of colour-blindness is satisfactory in that in red-green blindness, blue and yellow are the remaining colour sensations of the colour-blind. Further, his " red," which is a carmine or bluish-red, seems to form the second neutral band

of the colour-blind, and his "green," which is a blue-green, forms the spectral neutral band. But the greatest difficulty is to account for the two varieties of red-green colour blindness. Hering explained these as due to differences in pigmentation of the macula and lens. The same explanation was proffered to account for anomalous trichromatism. There is little evidence in support of, or against, this view.

The Ladd-Franklin Theory.—The Ladd-Franklin, or the Molecular Dissociation Theory, is based on the assumption that colour-vision is in the third stage of development. In the first stage, only the colourless sensations are experienced. These are produced by the decomposition of the grey molecule, which is still found undifferentiated in the rods. The outer range of atoms of the molecule become "torn off" in decomposition and produce a chemical substance which stimulates the retinal nerve endings. In the second stage of development, the outer range of atoms is affected by different vibration rates and the former single response is now split up into two classes corresponding to the sensations of blue and yellow. In the third stage of development the yellow response is broken up again into two parts, giving rise to red and green sensations respectively. The red and green are not complementary, and when the red and green atoms are simultaneously decomposed, they revert to the sensation of yellow. When the yellow and blue atoms are decomposed together, a white or grey results. When all three are stimulated, the original sensation of grey is produced.

Colour-blindness is explained as being an atavistic condition. Total colour-blindness is at the first stage of vision, red-green at the second stage, where blue and yellow have remained undifferentiated. The rarity of blue-yellow blindness seems to indicate that "blue and yellow were the primitive forms of colour-vision, and that red and green the last to be attained, are the earliest lost. This accords well, it will be noticed, with the Franklin theory, that the vibrating portions of the colour-molecule, which occasions 'red' and 'green,' are developed out of the portion whose decomposition occasions yellow."[1]

For a full description of the theory and explanation of the various colour phenomena see articles in *Mind*, N.S., 1893, II, by Ladd-Franklin, or *Colour and Colour Theories* (London, 1929).

[1] Calkins, *Introduction to Psychology*.

The Edridge-Green Theory.—The Edridge-Green theory lays great emphasis on the presence of visual purple in the rods only, which substance is the sole visual substance known. The function of the rods, according to this theory, is to form visual purple, but they take no part in visual sensations. (This view has been greatly criticized as it is opposed to the duplicity theory which is more or less established.) Although the cones are devoid of visual purple, Edridge-Green claims to have seen four canals or depressions which conduct the visual purple into the fovea, the centre of acutest vision.

The theory is based on the assumption that colour-vision has evolved. The spectrum appears first as grey, the first differentiation causes the two extremes of red and violet to appear, then green, then yellow, then blue, and finally orange. Sometimes a seventh colour, indigo, can be perceived. Colour-blindness is atavistic, and all these six stages are represented in travelling from colour-blindness to normal vision. This classification has been much disputed as also the order of appearance of the colours. For a full account of the theory see Edridge-Green's Hunterian Lectures.

CHAPTER II

HEARING

HEARING is, after vision, the sense department which is richest in experience. It is the basis of nearly all our daily intercourse. It is a main avenue for our knowledge of important aspects of the world around us. Through it music makes its wonderfully complex appeal to our æsthetic feelings and emotions.

All the sounds we hear can be divided into the two classes of musical sounds and noises. If we strike a note on the piano, or play a note on any other musical instrument, we hear what we call a musical sound. We describe as noises the ordinary sounds of the busy street, or sounds such as are made by the slamming of a door or the hiss of escaping steam. Musical sounds are usually pleasant and noises unpleasant, but this does not hold in every case. It must not be thought that the distinction between musical sound and noise is a sharp and absolute one, that every sound is either a musical sound or a noise. As a matter of fact we rarely hear a pure musical sound, a pure tone, for example, there being almost always an element of noise present with it, and, on the other hand, in many noises it is possible to distinguish some tonal element. The tuning of the musical instruments in an orchestra produces noise, yet that noise is a combination of many musical sounds.

Air vibrations are the normal stimulus for our auditory apparatus in the ear. The vibrations originate in a sounding body which is itself in vibration; they are communicated to the air, and through the air to the ear. When we accidentally strike a tumbler we cause it to produce a ringing sound, and we can easily feel its vibrations. If, by touching the tumbler, we cause the vibrations to cease, the sound ceases at the same time. In the same way we may notice the vibrations of a gong after it

has been struck, or the vibrating prongs of a tuning fork. In some musical instruments, as, for example, the flute or other wind instrument, the air is set in vibration directly by blowing. These air-waves strike the drum of the ear, and are conveyed inwards to the delicate mechanism of the inner ear, where they stimulate the receiving cells. The nervous impulses initiated by the changes in these cells are conducted by the fibres of the auditory nerve to the auditory centre in the brain.[1] When air-waves strike the drum of the ear at regular intervals, they are said to be *periodic*, and it is then that we hear musical sounds or tones. Noises are caused by *aperiodic* waves, or waves which fall irregularly on the drum.

A tone, then, is the result of a number [2] of air-waves striking the drum of the ear at regular intervals. The more rapid the vibration, that is, the more rapidly the waves succeed one another, the higher the note; the slower the vibration rate, the lower the note. This characteristic in a musical sound which makes us speak of it as higher or lower is termed its *pitch*. Thus the pitch of a musical sound or note depends upon the number of air-waves which strike the ear in a given period of time—we usually reckon in seconds in this connection. Middle C on the piano we speak of as having a vibration rate of 256 vibrations per second; C the octave above that has twice as many vibrations per second, that is 512.[3]

A note may vary in *intensity* when the same number of vibrations are reaching the ear every second, and the pitch remains, therefore, unaltered. Sometimes we hear the note loudly, at other times it becomes scarcely audible. What change is there in the air vibrations corresponding to the difference in intensity of the sound? If we arrange a simple piece of apparatus the cause will soon become apparent. We have already described the graphic method for the measurement of short intervals of time. This depends on the employment of a smoked drum. The drum is covered with paper, and then held over a smoky flame—from benzol or camphor—until the surface of

[1] See Appendix A.

[2] It was formerly held that at least two successive air waves must strike the tympanum before the sensation of tone was produced. Recent work ("L'Année Psychologique," vol. 24), would seem to show that a single wave may produce the tone effect.

[3] The Standard Note has varied from time to time. C = 256 is the Scientific or Philosophical Pitch and is extensively used in all scientific work. In International Pitch, A = 435, and the other notes vary accordingly

the paper is a smooth black. Such a smoked drum is rotated at a constant rate by clockwork or an electric motor. We take a tuning fork and fasten a light lever to one of its prongs. When the tuning fork is set in vibration the lever also vibrates with it. We bring the point of the lever lightly in contact with the smoked drum as it rotates, and the point traces out on the smoked surface the path of the vibrations of the fork, showing a series of movements to and fro in regular sequence like the swings of a pendulum. This tracing shows both the rate and the size or amplitude of the vibrations—a complete movement backwards and forwards being one complete vibration. As the sound produced by the tuning fork becomes fainter, we note that the size or amplitude of the vibrations is also becoming gradually less. If we count the number of vibrations registered every second, we find that this number has remained constant, as the pitch of the note has remained unaltered. Loudness and softness, therefore, appear to be due to differences in the size or amplitude of the vibrations. Noises also show differences in intensity in precisely the same way ; whether they also differ from one another in pitch, apart from any pitch differences of their tonal components, it is somewhat difficult to say.

There is a third way in which musical sounds may differ from one another. If we sound a note on the piano and then the same note on the violin, the resultant sound in the latter case, though of the same pitch as in the former, differs from it very considerably, so that no one listening has any difficulty in distinguishing the two. The reason is that neither instrument is giving us a pure tone. It is possible under certain circumstances to obtain a pure tone, but if all musical instruments produced pure tones it is certain that our liking for them would be considerably diminished. The musical note given by any instrument is always composed, not of one, but of a number of tones, the dominant or fundamental tone giving to the note its characteristic pitch. The complex sound, as a whole, is known as a clang. Every musical note, then, is such a clang, and is composed of one fundamental tone and a number of overtones, as they are called. This can be easily demonstrated in the case of a violin. If one string be sounded so as to produce a tone, say, of 300 vibrations per second, we shall find that other tones are also produced of 600, 900, 1200, etc., vibrations

per second. These latter are the overtones. The string vibrates, as a whole, at the rate of 300 vibrations per second, and it also vibrates in halves, in thirds, in fourths, etc., producing the higher tones of 600, 900, 1200, etc., vibrations. These overtones can often be distinguished by the practised ear. But, if the string is made to vibrate, and then lightly touched with a feather at its middle, or third, or quarter, etc., the corresponding overtone will ring out clearly, the other notes being damped. There is a simpler method still of demonstrating overtones. Hold down a note on the piano without sounding it, thereby raising the damper and giving the string freedom to vibrate. Then loudly strike the note an octave below and let it go. We shall hear vibrating the string of the note we are holding down, giving us the first overtone, and it then becomes easy to recognize this overtone in the note originally sounded. The other overtones can be easily distinguished in the same way.

If we wish to know exactly the vibration rates of overtones or of other tonal elements of a complex sound, we employ resonators. A confined chamber of air or a stretched string can act as a resonator. The string or the confined air is attuned to vibrate more readily at one particular rate than at any other rate, that rate being the rate at which it would vibrate in giving its own note. If the string or confined air be at rest, and waves possessing this vibration rate to which the string or confined air is attuned are travelling through the surrounding medium, these will be immediately thrown into sympathetic vibration. By resonators attuned to different tones we can thus pick out the different tones in the complex sounds around us—the overtones of musical sounds, and the tonal elements in noises.

It is the presence, absence, or relative prominence of particular overtones that gives to each musical instrument its own characteristic quality, and the difference in the note we speak of as its *timbre*. It is this also that enables us to distinguish one human voice from another. A pure tone without overtones is dull, lifeless, and flat—for example, such is the character of the notes of the flute, which are relatively poor in overtones. The tuning fork gives relatively pure tones, but we can often distinguish the first overtone, and also high overtones which are not harmonic.

Some psychologists[1] speak of musical sounds as possessing

[1] For example, James, Calkins, Watt.

a fourth characteristic. They claim that musical sounds, besides differing from one another in pitch, intensity, and timbre or "clang-tint," differ also in volume. This, however, is a much disputed point. Calkins writes: "The roar of the waves on the beach is not merely a deeper-pitched, nor always a louder, sound than the voice of the child at play beside them; it is also what we may call 'bigger,' 'vaster,' more 'extensive,' or more 'voluminous.' . . . This sound-bigness or volume, it should be added, varies with the pitch, for the lower the pitch the 'bigger' is the sound; yet volume is not identical with pitch." [1] Watt, who has recently done important psychological work on sound and music, writes: "The series of tones of simple pitch contains a variation of volume or mass. Low tones are great or massive and all-pervasive; high tones are sharp, thin, and circumscribed; as tones rise in pitch, their volume shrinks gradually, pulling itself together as it were, till it is finally too small and thin to be noticed." [2]

The pitch range of audible tones varies considerably with different people. A grand piano, which usually ranges from about 26 to about 4000 vibrations per second, does not nearly cover the range of tones we are capable of hearing. We can hear lower tones on the one hand, and very considerably higher on the other. As a result of careful investigation it has been estimated that the series of tones audible to the human ear extends from a note of 16 vibrations per second to one of about 22,000.[3]

Giant tuning forks have been devised for the production of the very low tones. Each prong is furnished with weights which are clamped on. As the weights are gradually moved towards the ends of the prongs, the tone becomes lower and lower. As it becomes lower the tone becomes very faint, and accompanying it we can hear a number of puffs. At a certain point the tone completely disappears, and we hear nothing but a series of separate puffs, each puff corresponding to one movement of the prongs. The point at which the tone becomes inaudible, leaving nothing but puffs, is the lower limit of hearing, or the lower *limen* or *threshold* of pitch.

[1] *Introduction to Psychology*, p. 93.
[2] *The Psychology of Sound*, p. 27.
[3] Some writers give a much higher upper limit, but it has been suggested that notes with a higher vibration rate are not heard as tones. What is heard is the noise made in their production

Tones having a vibration rate of over 22,000 are not heard as tones. If they are audible at all we hear merely a hissing sound with no tonal element. This upper limit of pitch can be determined in the same way as the lower with small and fine tuning forks. It is most conveniently investigated, however, by using the Galton whistle.[1] By means of a screw-cap the length of the bore of the whistle can be adjusted at will. When the bore is long the note is relatively low, and the whistle can be made to emit a higher and higher note by decreasing the length of the bore, which can be finely adjusted by means of a micrometer scale on the whistle. When the upper limit is reached, as we have said, a hissing sound alone is heard, and this, too, eventually becomes inaudible. Sensitive flames have been found to be affected by vibrations too rapid to be heard by the normal human ear. The upper limit of hearing has been found to become lower with increasing age, and it has been said that no one over forty can hear the squeak of a bat. Sir Francis Galton, the originator of the whistle, relates how he went through the Zoological Gardens in London with the whistle and an india-rubber bulb at the end of his walking stick. When the animals had become quite accustomed to the stick he would press the bulb, thus causing the whistle to sound. If the animals pricked their ears he took it to mean that they heard the sound. He found cats most sensitive of all as regards power of hearing shrill sounds.[2]

The complete tonal series must not be regarded as a succession of separate tones as in a keyed musical instrument; it is one continuum of tone. We can get the best conception of this by thinking of a siren. In the case of a siren the air is blown through a narrow tube so as to impinge on a large, round metal disc. This disc is perforated with a number of holes at regular intervals, and the current of air is stopped except when one of the holes is opposite the tube. The rate at which the disc rotates, and the number of holes in one ring round it, or the distance between contiguous holes, will regulate the number of puffs of air escaping in any period of time. The note given out can thus be varied at will with the rate at which the disc is rotated, and with gradually increasing rate we shall have a note continuously increasing in pitch—a continuum of tone.

Theoretically we can obtain the whole range of audible

[1] See Galton's *Enquiries into Human Faculty*. [2] *Ibid.*, p. 26.

tones from a siren. If we begin by rotating the disc very slowly, so that only 11 or 12 holes pass the tube in a second, we shall of course hear no note, but only a number of puffs of air, because the rate of vibration is below the lower threshold of tone audition. When the number of puffs is increased to 16, most of us will hear a very low note. As we gradually increase the rate of rotation, the note rises continuously in pitch, until it reaches the upper limit of tone audition. We have thus produced the whole tonal series as a continuum of tone.

Listening attentively to the changing tone produced by the siren through its whole range, we feel that sometimes we can tell immediately that the note has altered in pitch, and at other times we require to listen for a longer interval before we can appreciate any difference. Differences in pitch are most accurately discriminated over the middle part of that section of the tonal series which is employed for musical purposes. Here practised observers can detect differences of less than half a vibration. The differential threshold for pitch—so it is designated—is about a third to half a vibration over a moderately wide range in the middle of the part of the tonal series used in music. At the upper and lower limits of hearing pitch discrimination becomes much less acute, and near the upper threshold differences of a thousand vibrations often remain unnoticed. It is interesting to note that a difference can frequently be detected when the observer is unable to say which of two notes is the higher.[1]

When two tones which are not too close together in pitch are sounded simultaneously, other tones are heard in addition to the fundamental tones actually sounded and their overtones. Such additional tones are known as "combination tones." The objective source of combination tones is somewhat obscure, and in some cases they may possibly be subjective in origin. Where, as in certain cases, combination tones can be picked out by resonators, their objective origin cannot be doubted.

The most easily recognizable of the combination tones is that known as the first *difference* tone. Its vibration rate is given by the difference between the vibration rates of the two fundamentals. Thus if h is the vibration rate of the higher and l that of the lower, the first difference tone has a vibration

[1] In producing tones with the voice the musically gifted can vary a note accurately within limits of less than 1 vibration per second.

rate of $h - l$. Or, to take a concrete case, if we sound notes of 200 and 300 vibrations per second respectively, a difference tone of 100 vibrations per second is also produced, that is, a note which is an octave below the lower fundamental. Under favourable conditions other difference tones may be heard. Thus a second difference tone has a vibration rate of $2l - h$. This would represent the difference between the first overtone of the lower and the higher fundamental. Thus apparently the overtones of the fundamentals may also produce difference tones. In the concrete case given, this second difference tone would also be a note of 100 vibrations per second. Hence with two tones a major fifth apart (ratio 2 : 3), the combination tone an octave below the lower fundamental is particularly prominent. There is some doubt at the present time regarding the number of difference tones that may be heard, and recent work by Stumpf seems to indicate that the number is much more limited than was at one time supposed. In addition to the difference tones we may have a *summation* tone with a vibration rate corresponding to the sum of the frequencies of the fundamentals, that is, $h + l$, or in our concrete case, 500. If two tones have vibration rates of 400 and 500 respectively, and are sounded together, we would hear the summation tone of 900, the first difference tone of 100, a second difference tone of 300, and possibly other difference tones. Some of these combination tones may be heard by taking two tuning forks and sounding them.[1] These phenomena serve to explain in part the wonderful effects which can be produced in modern music.

If two tuning forks, both tuned to middle C (256 vibrations per second) are sounded, and held over resonating bottles,[2] the two notes produced are fused together, and we have perfect unison. If now one of these forks be mistuned—which can be done by adding a weight to the prongs, or, where that is

[1] Quincke's tubes may also be used. These are glass tubes of different lengths, constructed so as to yield notes of various vibration rates, and are very easily manipulated. If we sound one giving a moderately low note, and then introduce one giving a higher note, a low difference tone or a high summation tone, or both may be heard.

[2] These can easily be made. Take an ordinary glass bottle with wide mouth, part filled with water. Sound the tuning-fork and hold it over the mouth of the bottle. Add or pour out water till the bottle strengthens the sound of the fork to maximal extent. The bottle is then a resonator for this particular note.

impracticable, by filing the ends of the prongs to raise the pitch, or filing the prongs near the base to lower the pitch—a somewhat different result will be obtained. Suppose we have lowered the one tuning fork to 255 vibrations. When these two notes of 256 and 255 vibrations respectively are sounded together, once every second the two waves will reinforce one another, when their crests coincide, and once every second they will act against one another when the crest of the one coincides with the trough of the other. Hence there will be a continuous rising and falling in intensity of sound, technically known as "beating." The number of beats per second will be equal to the difference in vibration rate of the two tones—in this case one. With notes of 256 and 254 there will be two beats per second, with notes of 256 and 253 three, and so on. As the difference in vibration rates increases the beats become more numerous, until their rapidity causes them to be indistinguishable as separate beats, and therefore impossible to count. They will then be experienced merely as a "roughness."

If we continue increasing the interval the sensation of roughness in turn disappears, and we get the kind of experience we call *consonance* or *harmony*. Continuing still to increase the interval we get the roughness and then the beats reappearing, this time between the higher note and the first overtone of the lower. This effect can be made clearer if we think of the varying note as rising in place of falling in pitch, the other note remaining at 256. The first overtone of a note of 256 vibrations has a vibration rate of 512. When the varying note comes to about 500 vibrations per second, we get beating at the rate of twelve beats per second between it and this overtone. The roughness in the major seventh interval is caused in this way. As the varying note rises still more in pitch this beating becomes slower and slower, until it finally disappears once more when the notes are exactly an octave apart, the first overtone of the lower note being identical with the higher note. If a large number of overtones is present in the case of both notes a certain degree of roughness due to beating will rarely be absent, except in the case where the interval is an octave. But with the consonant intervals the slight roughness merely gives character to the combination. The assumption that the presence or absence of beating is the basis of our experience of discord or dissonance and harmony or consonance has frequently been challenged. Watt has recently (see *Psychology of Sound*

and *Foundations of Music*) rejected it entirely, and some psychologists, as, for example, Wundt, claim that the agreeableness of consonance or harmony at any rate is due to the presence of strong identical elements in the overtones of the combined notes. Whatever may be the ultimate explanation, it is clear that certain musical intervals give dissonance, and others consonance, and that some intervals give a higher degree of consonance than others. The most consonant interval is the octave, and after that, in order, the fifth, the fourth, the major third, and major sixth, the minor third and minor sixth. On the other hand the dissonant intervals are the major and minor second and the major and minor seventh.

The notes in a musical scale have constant relations to one another with respect to vibration frequency. The ratios in the Major Diatonic Scale (natural) are: tonic, 24; supertonic, 27; mediant, 30; subdominant, 32; dominant, 36; submediant, 40; leading note, 45; tonic, 48. Thus the ratio of the octave is 1 to 2, of the fifth 2 to 3, and so on. If we take middle C (written C′) as having a vibration frequency of 256, then C″ has a frequency of 512, and the intervening notes of the scale have the frequencies: D, 288; E, 320; F, 341·3; G, 384; A, 426·6; B, 480. This represents what we have called a "natural" scale, and the unaccompanied human voice singing these notes would give these frequencies, if singing "true." Owing to practical considerations with key instruments, however, it has been found necessary to diverge slightly from this "natural" scale, in all the notes except the tonic or keynote and its octave, in order to avoid an impossible multiplication of keys. Thus, what is called a "tempered" scale has come into existence, and the ratios of the notes in an octave of the piano are: 1, $2^{\frac{2}{12}}$, $2^{\frac{4}{12}}$, $2^{\frac{5}{12}}$, $2^{\frac{7}{12}}$, $2^{\frac{9}{12}}$, $2^{\frac{11}{12}}$, 2, or 1, 1·123, 1·260, 1·325, 1·498, 1·682, 1·888, 2, the octave being thus divided into twelve equidistant semitones. The divergence of each note, except the tonics, from the notes of the "natural" scale is never as much as 1 per cent., the greatest being in the submediant (1·682 and 1·667).

To complete our discussion of the qualitative investigation of sound sensations a brief account may be given of the more important theories which have been formulated to explain our auditory sense experience. The most widely accepted theory, although its acceptance is not universal, is that of Helmholtz. Helmholtz bases his theory on the physical principle of

resonance. He regards the *basilar membrane* [1] as composed of a number of vibrating fibres or strings, such as we find in the piano. Each string vibrates in its own particular period, and each string picks out from any complex sound entering the ear that element which is approximately its own vibration rate, and resounds to that. If no such element is present as far as any fibre is concerned, then that fibre does not vibrate. A note of 100 vibrations entering the ear will cause one fibre of the basilar membrane to vibrate maximally in sympathy, the fibre whose natural vibration rate is 100. In addition, the fibres, having the same vibration rates as the overtones, will also be thrown into vibration. A complex note is therefore not received as a complex note, but causes the vibration of a number of separate fibres of the basilar membrane, and is thus analysed in being received.

The theory of Helmholtz is supported by cases of tone deafness. Certain notes alone may be inaudible to some people, who can hear all other notes perfectly. This can be accounted for by imagining the failure of some of the fibres of the basilar membrane to respond. In one difficult experiment which was carried out,[2] it was found that dogs become deaf to high tones when the lowest whorl of the cochlea is destroyed, and to low tones when the highest whorl is destroyed. This is the result one would expect if the Helmholtz theory is sound; for the fibres of the basilar membrane increase in length from the base to the apex of the cochlea, having the short fibres at the base which will respond to high notes, and the long fibres at the apex which will respond to low notes. Cases of "tone deafness" and "islands of hearing" in the human subject [3] also support the theory.

It is difficult, however, to imagine the fibres of the basilar membrane, which only range in length from ·04 to ·49 mm., responding to tones which range from 16 to 22,000 vibrations. Only by a very great weighting of the fibres could this become possible. Further, the rods of Corti, which rest on the basilar membrane, and which act as dampers to the vibrating fibres, must have the effect of greatly curtailing the freely vibrating parts of the fibres. Apart from this difficulty, however, the

[1] See Appendix A.
[2] Quoted by Myers, *Experimental Psychology*, vol. i., p. 48.
[3] *Ibid.*, chap. iv.

theory serves to explain most of the facts of the hearing of musical sounds.

In consequence of the difficulty of conceiving how the basilar membrane can exhibit resonance in the manner required by the Helmholtz theory, Ewald suggested a different explanation of our tone audition and pitch discrimination. By experimenting with an artificial basilar membrane on which he arranged a fork to vibrate, he found that each tone caused a series of wave-pictures to be formed on the membrane, which he could photograph, and that each tone produced its own characteristic wave or sound picture, while noises produced a series of ever-changing sound pictures. Ewald suggested, therefore, that each tone produces its own sound picture as a whole on the basilar membrane, and that the hair cells stimulated according to this sound-picture are responsible for the phenomena of tone audition. This theory, however, requires a much more complete development, parallel with experimental investigation, before it can take its place with the older theory.

The most recent theory is that of Watt. He entirely rejected the resonance theory, and, approaching the phenomena neither from a physical nor from a physiological, but from a psychological point of view, he proposed a theory which is, he claimed, in accord with the psychological facts and not inconsistent with any known physical or physiological facts. This, he maintained, is all that can reasonably be required of the psychologist. The basis of Watt's theory is his view that sounds have a quasi-spatial character or attribute of volume, together with his contention that pitch represents, not a qualitative, but a positional difference between notes. As the sound-wave passes through the cochlea it exerts pressure on the basilar membrane, and this is, as it were, bent out, the extent bent out corresponding to the wave-length and giving the attribute of volume to the sound sensation. Corresponding to the crest of the wave in the case of a pure tone there will be a point of maximal displacement of the membrane, equidistant from where the displacement begins and where it ends. This will give the pitch of the tone. Where more than one tone is present, as in a clang or chord, the lowest determines the total extent of the basilar membrane displaced, the other displacements being superposed upon this, with maximal displacements corresponding to the several pitches of the various tones involved.

Expressing it in this brief way scarcely does justice to Watt's

theory, which is, as we have said, primarily psychological. His psychological analysis of our experience of musical sounds led him to the view that such sounds present themselves to us as masses with prominences showing a definite and orderly pattern. In music there is therefore always a single continuous, though varying, volume of sound, with prominences in orderly arrangement and succession, and it is the form of the total volume with these prominences that gives rise to our experience of consonance, dissonance, melody, and so on. Melody represents, as it were, orderly movement. Not the least interesting point about the theory is the way in which it brings music into line with the other great forms of art.[1]

In discussing the upper and lower limits of tone audition we have already had to refer to quantitative experimentation; for all determinations of thresholds are necessarily quantitative experiments, and are carried out by the employment of one or other of the psycho-physical methods. Quantitative methods are also employed in testing an individual's delicacy of pitch discrimination. This is really testing the individual's musical ear, though it is an entirely different kind of test from that ordinarily employed under the name of "ear test." The ordinary "ear test" is mainly a test of musical memory. In testing an individual's pitch discrimination we employ two notes—as nearly pure tones as possible—one being taken as the standard, the other as the variable. The notes may be given by practically any source allowing of a sufficiently fine grading of the pitch, but are most conveniently given by tuning forks or stretched piano wires. Spearman's dichord with two stretched wires is, perhaps, the most suitable arrangement. We may employ the Method of Limits, the Method of Serial Groups, or the Method of Right and Wrong Cases. The simplest procedure is by the first or second of these methods. The standard is first sounded, both wires damped, and then a variable sufficiently different to be easily distinguished as different is sounded, and both wires damped once more, the object of the damping being to eliminate any resonance, and to keep the duration of the notes equal and constant. Care should be taken to secure that both notes are sounded with the same intensity. Bringing the variable nearer and nearer to the standard by lengthening or shortening the wire, as the case may be, by

[1] *Psychology of Sound* and *Foundations of Music*.

constant gradations, we ultimately get a variable which the subject fails to distinguish from the standard. We then begin an ascending series (or descending) with the variable indistinguishable from the standard, and increase the difference until they are discriminated. Thus we determine the length of wire at which the variable is just distinguished from the standard. Sounding the note at this length simultaneously with the standard, and counting the beats per second, we obtain the threshold in vibrations per second. Through the middle range of the musical scale, as we have already seen, the good musical ear can distinguish differences of $\frac{1}{3}$ to $\frac{1}{2}$ of a vibration per second. Such differences, however, cannot be reproduced even by the musically gifted. A difference of about ·9 of a vibration appears to represent about the limits of accuracy in reproduction of a note.

An interesting phenomenon frequently appears when two notes of the same pitch are presented separately to the two ears. They may be judged to be different in pitch. This difference in pitch of the two ears can be tested and measured quite simply by means of tuning forks. The experimenter tests the forks beforehand to make sure they are producing the same tone. The two forks are then struck simultaneously and held one to each ear of the subject in immediate succession—one to the right ear, and then the other to the left. The subject may judge them different in pitch. The pitch of one is altered by filing or by adding a little wax to the prongs, until the subject says the two are identical in pitch. By striking the forks and holding them over a resonating bottle we can now count the number of beats per second, which gives us the number of vibrations per second by which the one fork differs from the other, and, therefore, the pitch difference of the two ears.

Quantitative methods may also be applied to the study of auditory acuity. It is a well-known fact that individuals differ in their ability to hear sounds. Not only does acuity of hearing vary with individuals, but it varies with the same individual according to his condition. It is somewhat difficult to test, or rather measure, acuity of hearing satisfactorily, owing to the difficulty of procuring a standard sound of constant pitch and intensity. We generally test practically by means of a watch. No measurement is possible with a watch, but for practical purposes it answers sufficiently well, except that the quality of the tick, like that of any similarly complex sound,

alters considerably with its distance from the ear. The essential condition for the test is quietness and freedom from all external and disturbing sounds. The ears ought to be tested separately. One ear is plugged with cotton wool, and the subject is seated with the other ear in line with the source of sound. The experimenter begins by holding the watch so near the subject that its tick is plainly audible. The distance is increased by equal gradations until the subject reports that the ticking is no longer audible. A series is then taken, beginning with the watch so far away as to be inaudible, and the distance being gradually diminished until the subject reports that he can once more hear the tick. The mean of the last distance at which it was heard in the first series and the last distance at which it was not heard in the second gives us the threshold distance, which we take as measuring the auditory acuity of the ear tested. To obtain accurate results each series should be repeated at least five times.

Other methods of testing which have been devised depend upon the fall of a solid object from a definite or variable height. The intensity of the sound can be varied either by varying the distance from the subject or by varying the height of the fall. A simple apparatus of this kind is Politzer's Acoumeter. This gives a fairly constant sound, and testing with it is conducted in the same way as with the watch, but greater distances are necessary, since the sound made by the acoumeter carries a good way. Wundt's Fall-phonometer is another piece of apparatus for a similar purpose. It differs from Politzer's apparatus in giving a variable height of fall. A more elaborate piece of apparatus still is Seashore's Audiometer, one of the chief advantages of which is that it can be used in a much more restricted space.

Weber's Law does not hold of the differential threshold for pitch. It does hold through a wide range in the case of the differential threshold for intensity. For noises we must increase the intensity by approximately one-third (measuring in terms of the height of fall) before the difference is appreciated. Tonal intensities are very difficult to study experimentally, but apparently Weber's Law also holds of these, though comparatively little reliable work has been done.

CHAPTER III

CUTANEOUS SENSATIONS

CUTANEOUS sensibility represents the most primitive of all sense departments. Pressure, cold, warmth, are sensed far down the animal scale, and probably at its lowest extreme. All the other senses may be looked upon as developed from a primitive sense of "touch." In all cases receptors have been evolved which were specially adapted to be excited by particular kinds of "touch," by ethereal vibrations, by air vibrations, by molecular vibrations, and so on. In the cutaneous surface itself receptors have been specialized to respond to different kinds of stimuli, and to originate the specific sensations grouped under the head of cutaneous sensibility. Thus, there are in the cutaneous surface receptors for pressure, for cold, and for heat, while pain sensations are mediated by free nerve endings in the cutaneous and subcutaneous tissue.

Our modern knowledge of cutaneous sensations depends largely on work done by Head and his colleagues,[1] and our discussion may fittingly, therefore, be introduced by an account of this work, the results of which were first given to the world in the Marshall Hall Address before the Royal Medical Society in 1905. On the 25th of May, 1903, Dr. Head's radial and external cutaneous nerves were divided at the elbow, small portions excised, and the ends sutured. As a result, all forms of cutaneous sensibility were lost over a wide area of the forearm and back of the hand, the previous sensory condition of which had been carefully examined and found to be normal before the operation. But the loss of cutaneous sensibility did not involve the loss of all sensibility to pressure. "Stimulation with cotton-wool, the prick of a pin, the application of all forms of heat and cold, were unappreciated, and the two points of the compasses could not be discriminated [2] even when separated to the farthest

[1] *Brain*. [2] See chap. vi.

extent possible. But stimulation with the point of a pencil "was at once appreciated, and the point of application localized with remarkable accuracy." Further, in a test utilizing "the irregularities in an otherwise smooth surface the hand that had been robbed of all its cutaneous sensibility was found to be actually more sensitive than a similar part on the normal side."[1] When, however, the skin was lifted so that the pressure did not affect the subcutaneous structures the pressure was no longer felt. The sensibility remaining, therefore, after the operation was a deep sensibility in the underlying muscles. In the skin itself over the affected area there was no sensitivity to pressure, contact, cold, heat, or prick.

Seven weeks after the operation sensations due to prick began to be appreciated. These pain sensations, however, were not localized, but radiated widely and were frequently referred to points at a considerable distance from the point stimulated. When sensibility to cold and heat was found to have returned, sensations were produced by ice, and by water at 50° C., but there was no sensitivity whatever to temperatures between about 24° and 38°. The cold and heat sensations obtained were found to be due to cold and heat spots in the cutaneous surface, first described by Blix and more carefully studied by Goldscheider.[2] Hence, along with the sensibility to prick, these spots, sensitive to extreme heat and extreme cold respectively, made their reappearance before there was any other trace of cutaneous sensibility. The spots "were set in an area insensitive to temperature stimulation. The cold spots might be stimulated by any temperature below 24° C., and when they were stimulated they reacted explosively, the sensations not being localized but radiating widely, as in the case of the pain produced by prick. The behaviour of the heat spots, which might react to a temperature from 38° upwards, was similar. Experiments carried out on these cold and heat spots showed that they were incapable of giving "graduated sensations of heat or of cold." At the same stage of recovery movement of the hairs on the skin "produced a curious widespread formication, with the same reference to distant parts as in the case of temperature and pain." But at this stage there was no sensitivity to light touch or to warm or cool degrees of temperature.[3]

Thus the operation had, apparently, resulted in the dis-

[1] *Brain*, vol. 28, 1905. [2] *loc. cit.* [3] *loc. cit.*

tinguishing and separating of two forms of cutaneous sensibility, one of which gave qualitative experiences of pain, cold, heat, and a peculiar kind of "touch," without quantitative gradation or definite localization, or discrimination of simultaneously applied contacts; the other gave experiences of warmth and coolness, and of light touch, with gradation, localization, and discrimination. The first form of cutaneous sensibility was termed *protopathic*, the second *epicritic*. Both are present normally, together with a deep sensibility to pain and pressure. When both are absent deep sensibility may still be present, and protopathic sensibility may be present without epicritic. When protopathic sensibility is present without epicritic, characteristic differences manifest themselves, even with regard to sensations which are due to the protopathic element in normal sensibility. That is to say, the development of epicritic sensibility means not only the addition of sensations not previously obtained, with gradation, localization, and discrimination, but means an alteration of all cutaneous sensations.[1]

The qualitative study of cutaneous sensibility in the laboratory is carried out in the main by punctate stimulation of the cutaneous surface. Consequently the protopathic element is, perhaps, somewhat over-emphasized, and the student is apt to get a somewhat one-sided and distorted notion of the nature of cutaneous sensibility, which it is by no means easy for him to reconcile with his everyday experience. Quantitative work might form some sort of corrective, but, unfortunately, quantitative work on cutaneous sensibility is seldom done except by advanced students. The most satisfactory procedure in this case, therefore, would seem to be to begin with the study of certain phenomena which are more or less characteristic of all departments of our sensory experience, and thus incidentally to gain some general acquaintance with cutaneous sensibility in its integrity.

Let us start with the phenomena of accommodation. If an object of moderate weight—a cork, for example—weighted with some lead—is placed on the cutaneous surface, say, of the forearm, we experience at first a sensation of pressure. Gradually we become less conscious of the pressure, and in a little while the sensation has entirely disappeared. The cutaneous surface has become *accommodated* to the pressure. Only when the pressure is quite constant can accommodation take place. Any change of intensity in the pressure makes itself felt immediately.

[1] Subsequent investigations by Boring and by Schafer throw considerable doubt upon the accuracy of Head's observations.

In all sense departments, indeed, it is primarily change that gives rise to sensation. If, when the cutaneous surface has become accommodated to the pressure, the cork is removed, we experience after-sensations more or less analogous to the after-sensations in the case of vision, which have been already described.

Analogous phenomena can also be obtained with temperature sensations. There is accommodation to warmth and coldness, and after-sensations, both positive and negative, are especially prominent in the case of cold. The glow of warmth felt after coming out of a cold bath is partly due to negative after-sensations. A striking illustration of the phenomena of accommodation to warmth and coldness may be obtained by preparing three bowls or basins of water. To begin with, all three are at the same temperature. The right hand is placed in one bowl, the left in another. The water in which the right hand is placed is gradually heated, say, to 45° C., and that in which the left hand is placed gradually cooled, say, to 5° C. If the heating and cooling respectively are very gradual the subject may not be conscious of any change of temperature. Both hands are now placed together in the third bowl, the water of which has remained at the temperature of the room, say, 10° C. To the one hand this water will appear cold, to the other, warm. The sensations of warmth and coldness, therefore, seem to depend on the relation of the temperature of the stimulating object to the physiological equilibrium of the moment, as that has been determined by the immediately preceding accommodation process. In this case the one hand had been accommodated to a temperature of 45° the other to a temperature of 5°.

The ordinary method of qualitative study of cutaneous sensibility, as we have already indicated, is by punctate stimulation. If we mark off a small area of the skin, for example, on the back of the hand between the second and the third metacarpals, and explore it with a pointed metal cylinder which has been cooled in ice water, we shall find that a cold sensation, often quite sharp, is experienced at definite points. These points—the so-called "cold spots"—are somewhat irregularly distributed, occurring either as isolated spots, or in chains or clusters. Warming our cylinder in water to about 50° C., we shall find heat sensations similarly given at definite points. "Heat spots" are not so numerous as "cold spots." They are, however, distributed in much the same way, except that

clusters of chains of spots are rather less frequent. The "heat spots" react more slowly than the "cold spots," and the sensations tend to radiate to a greater extent. "Touch spots" can be found in the same way by exploring the marked area with a stout hair mounted on a wooden handle, and "pain spots" by exploring with a mounted bristle. Pain spots are most numerous of all on the cutaneous surface as a whole. Certain areas, however, are quite free from pain spots, as, for example, an area on the inside of the cheek, and in the same way other areas are characteristically areas where one kind of spot is predominantly present, and another practically absent.

In all these experiments we have employed the kind of stimulus which is naturally calculated to evoke the respective sensations. Such a stimulus is called the *adequate* stimulus. We may, however, evoke the sensations in all cases by electrical stimulation, using a copper wire with the end rounded to a small bead, the electrical stimulus being given from the secondary terminals of an inductorium. This stimulus may be applied to the different spots already located in the area which we have explored, and it will be found that each responds with its own sensation. Such a stimulus is *effective*, but not adequate.

If we examine the structure of the skin we find embedded in it a great number of bulbs and corpuscles, which form the termini for nerve fibres. These are believed to be the receptor organs for cutaneous sensations. The end-organ of Ruffini is supposed to originate sensations of warmth, while the bulb of Krause is said to yield us our sensations of cold. The corpuscles of Meissner and of Pacini, and the nerve endings at the roots of the hairs are usually regarded as the receptor organs for touch. Pain appears to be represented by no special end-organ, and is probably associated with the free nerve endings. These are found to be very numerous in areas of the skin which are highly susceptible to painful stimuli, as, for example, the cornea of the eye, that is, the transparent covering in front over the iris and the pupil, while on the other hand in the area of the inside of the cheek, which we have already seen to be insensitive to pain, free nerve endings appear to be absent.

The tips of the fingers are crowded with Meissner's corpuscles, and these are areas which are particularly sensitive to contact or touch. Meissner's corpuscles seem to serve as the main receptors for contact on all hairless surfaces. A touch spot is also found at every hair root. The end-organs of Krause

are found in large numbers on the forehead, and on the inner surface of the eyelid, which are highly sensitive surfaces as far as cold is concerned. Heat spots—and possibly end-organs of Ruffini—are numerous on the surface of the cheek, and, as Halliburton points out, it is to the cheek that the washerwoman holds her iron when forming an estimate of its temperature. It has been calculated that there are between two and four million pain spots on the surface of the body, about half a million each of touch spots and cold spots, and a slightly smaller number of heat spots.

As a rule we obtain from each spot only its own sensation. Thus, cold spots give only sensations of cold. If we stimulate one with a metal rod heated to a temperature from 45° to 50° C., we shall get a sensation not of heat but of cold, provided we get a temperature sensation at all. Such a sensation is usually spoken of as a paradoxical cold sensation. We do not get a paradoxical heat sensation in the same way by stimulating a heat spot with a cold rod. If we thrust a needle into a cold spot we feel no sensation of pain, and if we touch one lightly with a hair we feel no sensation of contact or pressure. In both cases, if there is a sensation at all, the spot will give its own particular response of cold. Analogous phenomena occur in all four cases—heat, cold, touch, pain; each spot yields its own sensation and no other. If we simultaneously stimulate a heat and a cold spot we experience a sensation of the kind we describe as "burning."

We do not notice the punctiform distribution of sensitivity in the skin because ordinarily large areas are stimulated together at any particular time. It is only when we explore the skin by punctate stimuli that we discover its lack of uniform sensitivity. We have spoken of pain spots as if pain was experienced only as a result of the stimulation of particular free nerve endings. There is a sense in which this may possibly be true, but pain is also experienced in association with the other cutaneous sensations when the stimulus reaches a certain intensity. Too great intensity of stimulation will produce pain in the case of all receptors. Quick changes of intensity in the stimuli giving temperature sensations will also produce pain. For example, a sudden increase of heat will be experienced as pain, whereas, if the same degree of heat is slowly attained, no pain will be experienced. The latter fact explains how in certain circumstances great injury may be done to the organism

without the usual danger signal being made. On the other hand, a sudden blow, such as that from a bullet, may deaden pain, while the same pressure applied slowly to and through the skin will cause intense agony. Strong emotional excitement also seems frequently to dull the pain sense, as we shall see later, and a person labouring under a strong emotion may receive a serious hurt without being aware of it at the time.

It is a well-known fact that a man who has had a limb amputated may feel pain in that limb. Such a pain is known as a "propagated" pain. The pain really originates in the nerve trunk, but is located at the terminus of the nerve, and in this case in the lost limb. There are two kinds of propagated pains. The kind just mentioned is a *referred* or *projected* pain; the other kind is where the pain originates in one nerve, and is, as it were, transferred to another, as when eye defects cause pains in the forehead. This latter is known as an *associated* pain.

The adequate stimulus for cutaneous pain is damage or threatened damage to the skin. The adequate stimulus for tactual sensations is usually mechanical, such as the pulling out or pushing in of the skin. If, however, the arm be placed in a basin of warm water, the contact is not felt uniformly over all that part of the arm which is immersed, but only at the upper surface of the water, where it is felt as a ring round the arm. The reason for this is that at the surface of the water there is a pressure gradient, and a pressure gradient is a touch stimulus.

The sensations of tingling and itching may also be included under tactual sensations. Myers suggests that these are partly caused by reflex contractions of some of the muscle fibres attached to the skin. The sensation of tickling is remarkable for the extensive and intense sensation, and motor response, which can be produced by a very weak stimulus.

The sensations derived from the cold, heat, and pain spots retain much of their protopathic character, even when epicritic sensibility is present. The cold spots especially tend to react explosively. The heat spots again give very indefinite localization. Areal stimulation on the other hand gives sensations with true epicritic character. The anatomical basis of this epicritic character is rather obscure, and the work of Head and his collaborators really does very little to remove this obscurity. Degrees of warmth and coolness, which fail to

excite the cold and heat spots are, nevertheless, appreciated; similarly light touch, as by stimulation with cotton-wool, gives definite sensations of contact. These characteristics of epicritic sensibility are not explicable on the basis of the results obtained in punctate exploration of the cutaneous surface.

Quantitative Experiments.—Quantitative experiments on cutaneous sensibility are of considerable interest and importance, but involve technical difficulties to a considerable extent, as we have already indicated. Thresholds may be determined for each of the kinds of sensibility, as well as for the ability to discriminate two points simultaneously applied to the skin. The latter we shall have to consider when we come to deal with space perception. Of the others, sensibility to pressure and to pain are the most deserving of notice.

The threshold for pressure may be determined in either of two ways. We may employ weights, or we may utilize the elasticity of a spring or fibre. There is considerable variety of apparatus available in both cases, some arrangements being very elaborate, in order to allow for the somewhat complex factors which are involved in the actual carrying out of the experiment. Scripture's Weights and von Frey's Hairæsthesiometer may be taken as simple examples of the two types of apparatus. Scripture's set of weights consists of 20 cork discs, 3 mm. in diameter, suspended by silk threads from short handles. The weights range from 1 to 30 milligrams, with a difference of 1 milligram for the first ten, and 2 milligrams for the remainder of the series. The weights must be set down evenly on the area of the skin to be investigated. There must be no jerking of the thread either in placing them down or in removing them. The method of limits with haphazard order is specially applicable under the circumstances. Care must, however, be taken at each sitting to avoid fatigue of the part of the skin being studied.

Von Frey's Hairæsthesiometer consists of a hair (horse or human) attached to a thin wire sliding in a metal tube. On the outside of the tube is a millimeter scale, and this indicates the length of projecting hair. The method of limits is used—either regular or haphazard—to determine the threshold in terms of the length of projecting hair at which pressure is felt when the hair just begins to bend. This is converted into milligrams at the end of the experiment by placing the hair in the position that has been determined on the pan of a balance, and finding the weight equivalent to the pressure at which it bends.

The quantitative study of pressure sensation is historically interesting because of the fact that the beginnings of quantitative work in experimental psychology were made in this field. Weber established his law in connection with the discrimination of pressures on the cutaneous surface, and this led in Fechner's hands, as we have already seen, to the development of that branch of experimental psychology which he called *psychophysics*, and which is still frequently so designated. The difference threshold for pressure has been found to be about $\frac{1}{20}$th of the initial pressure, and Weber's Law holds approximately for moderate pressures.

The method of determining the threshold for pain is very similar to that for determining the threshold for pressure with von Frey's Hairæsthesiometer. The usual apparatus, called an algesimeter, is indeed constructed on a somewhat similar principle, the pressure exerted by a sharp point being balanced against the tension of a spring, and that, in turn, registered on a scale. If we wish to determine the threshold for deep pain a considerably modified form of apparatus must be used, the sharp point being displaced by a circular surface. Cattell's algometer is the most familiar apparatus of the latter type.

CHAPTER IV

SENSATIONS OF TASTE AND SMELL

SENSATIONS of taste and smell are not so complex as those of vision and hearing. They communicate to us a much simpler world. It is also much more circumscribed. The stimuli affecting vision and hearing may be at a distance from the respective sense organs, but with taste and smell the stimuli must be in close proximity or in contact. It may be thought that the organ of smell should be considered a distance rather than a contact receptor. In a way this is true. But the particles of the odorous substances which stimulate the olfactory cells must pass in respiration into the nostrils and be in contact with the sensitive surface there before a sensation is experienced. In any case the radius of action, so to speak, of the smell receptors is much more limited than that of the visual or auditory receptors.

Taste and smell are very closely associated, more so, indeed, than is generally supposed. If it were not for our olfactory sensations most of our daily food would be almost, or quite, "tasteless." This may seem an extreme statement, but it can easily be verified by any one who cares to do so. If we plug our nostrils with cotton-wool, and then place in succession on the tongue a small piece of onion and a small piece of potato or apple, we shall find, however incredible it may appear to one who has not tried the experiment, that we are totally unable to say which is which. The reason is that we have eliminated the co-operation of our olfactory sensations, which so largely assist in giving us the "taste" sensations which we normally experience. Tea, coffee, and quinine, all taste the same if we exclude the olfactory sensations in the complex "tastes" with which we are familiar; tea and coffee may still be distinguishable, but only because of the astringency of the former. In the same way when we are suffering from a severe cold, the nasal

passages are blocked, and in consequence we find all our food very "tasteless."

Taste.—The end-organs for taste lie in the tongue and also in the soft palate.[1] These so-called "taste-buds" must be stimulated before any sensation of taste can be experienced. The taste-buds occur in clusters, or papillæ, of various kinds, which are quite visible on the upper surface of the tongue. The fungiform papillæ are easily noticed from their red appearance, and the circumvallate papillæ form open delta-shaped clusters at the root of the tongue. Taste is only experienced when these are stimulated. The tongue, however, yields other sensations in addition to taste. If a crystal of quartz is placed on the tongue we experience a sensation of cold, and a sensation of pressure, but no gustatory sensation. The whole of the tongue yields touch and temperature sensations. If a pinch of sugar is placed on the tongue a different experience is the result. We get touch and temperature sensations as before, but with the stimulation of the taste-buds we get in addition the gustatory sensation of sweetness. The addition of smell to taste, temperature, and touch sensations gives us the complex experience we call the flavour of foods. Taste is more widely distributed with children than with adults. With the latter the middle of the tongue gives no sensation of taste, whereas in children taste-buds are found there, and also in the mucous membrane of the cheek. If our subject had been an adult and the pinch of sugar had been placed on the middle of the tongue, no taste sensation would have been experienced.

By means of careful exploration of the surface of the tongue it has been found that four kinds of taste sensation, and four only, can be elicited. Moreover, these are in part differently located. The sensations are bitter, sweet, sour or acid, and salt—the tastes given respectively by quinine, sugar, lemon-juice, and salt. Certain papillæ yield only one kind of sensation, others yield two, three, or even four kinds. The tip of the tongue is best for sweet and salt sensations; the back gives the sensation of bitter; the two sides give the sensation of sour or acid in highest degree. Some tastes, as for example a metallic taste, are complex, and not simple. A metallic taste is said to be due to a mixture of sweet and salt. Nausea, contrary to general opinion, is not a taste sensation, but an organic sensation, under which head it will be discussed later.

[1] See Appendix A.

Since certain regions of the tongue, as the front and the back, yield only one quality of taste sensation, it may happen that the same substance gives different tastes in different regions of the tongue. Sulphate of magnesium (Epsom salts) tastes bitter at the back of the tongue, but may be experienced as sweet at the tip. Similarly, saccharine tastes sweet at the tip of the tongue, but bitter at the back.

In all experiments that we carry out in studying gustatory sensations it is desirable that the substance to be tasted should, if possible, be presented in the form of a solution. In any case it must pass into solution in the mouth before it is tasted at all. Insoluble substances are tasteless. Moreover, a piece of sugar if placed on the tip of a tongue that has been thoroughly dried will seem tasteless until the tongue has become moist enough again to dissolve some portion of it. The solution employed, on the other hand, should not be swallowed, since in that way, if at all volatile, it may reach and stimulate the olfactory region through the passage at the back of the nose, and the results of the experiment may thus be vitiated. The usual method of procedure in taste experiments is as follows: The experimenter, employing a magnifying glass, draws a map of the subject's tongue, sketching in the contours and any prominent papillæ. These are numbered, and the experimenter stimulates these in the experiment. The subject sits as comfortably as possible. His eyes are closed and his nostrils are plugged with cotton wool. At the word "ready" given by the experimenter the subject presses his tongue against the roof of the mouth, thereby removing excess of moisture, and then he extends it. The experimenter takes a camel's hair brush, dries it, and dips it once or twice into the prepared solution which is to be employed in the experiment. Then he places the brush gently on the selected papilla and holds it there for two or three seconds. The subject may recognize the taste before the brush is withdrawn, in which case he signifies his recognition to the experimenter. Sometimes, however, a considerable interval of time may elapse before the subject can satisfy himself that he recognizes the taste. The tongue is not withdrawn until the decision can be given. The mouth is then thoroughly rinsed, and everything is ready for the next experiment. A temperature of about 40° F. is most favourable for taste discrimination. It appears that temperatures above or below that tend to dull, and even paralyse the taste-buds. If the mouth is rinsed with cold water

or with hot water, a solution ordinarily perceived as bitter or as sweet may become practically tasteless.

Such experiments as that described have yielded interesting results, some of which have already been noted. Tastes like metallic and alkaline indicate phenomena in the gustatory sense department analogous to the phenomena of colour-mixing in vision. It is, however, rather difficult to produce complex taste sensations by synthesis, because although we can combine the odour with the taste, the touch and temperature sensations, as well as organic sensations of an agreeable or disagreeable nature, are essential before the total complex experience is attained. There are other analogies to colour-vision. Just as in vision two colours may neutralize one another so as to produce a colourless combination, so in tastes one solution may neutralize another, and the combination be tasteless. Thus a salt solution of a certain strength may be practically neutralized by a sweet solution of appropriate strength. The same is true regarding an acid solution. The sourness of a fruit may be neutralized to a considerable extent by sugar. This phenomenon is known as *compensation*. Sometimes, however, tastes conflict with rather than neutralize one another. In that case we experience now the one taste now the other. This is known as *rivalry*, and again we can get an analogy in colour vision.

Taste also exhibits the phenomena of contrast both simultaneous and successive. The phenomena of simultaneous contrast can be easily demonstrated. Dry the tongue as before, plug the nostrils, and let the subject close his eyes, or, if we are our own subjects, keep the eyes open and use a concave mirror to see the tongue. Apply simultaneously a drop of salt solution to one side and a drop of distilled water to the other side of the tongue. It will be found that the distilled water tastes sweet. If a drop of a weak solution of sugar—weak enough for the taste to be practically inappreciable—be applied instead of the distilled water, the salt solution will markedly intensify the sweetness of the sugar solution. Salt has a much stronger effect in inducing sweet than sweet in inducing salt, although sweet will slightly intensify a salt solution. The effect of sweet on distilled water, however, is not to make it salt by contrast, but to make it sweet. In performing these experiments care must be taken to prevent the solutions mixing on the tongue. The phenomena appear the more remarkable when we remember that the two sides of the tongue are supplied with nerves connected with opposite hemispheres of the cerebrum.

Successive contrast may be obtained in much the same way. It is of course a familiar fact that eating sweets makes us more sensitive to acid tastes. In performing experiments on successive contrast the inducing solution must, as a rule, be strong. If the mouth is filled with a strong salt solution, then rinsed and filled with a weak sugar solution, the contrast effect will be clearly perceived. Distilled water will serve instead of the weak sugar solution. The same kind of effect is produced when salt and acid, or sweet and acid solutions are employed. The latter two do not give simultaneous contrast. Bitter is the only taste that cannot be produced by contrast.

Some of the effects of drugs in producing *ageusia*, or loss of taste sensation, are interesting. Cocaine temporarily inhibits the sensation of bitter. The leaves of the tropical plant *gymnema sylvestre*, if chewed, appear to abolish for a time the tastes of both sweet and bitter, leaving salt and sour unimpaired.

Quantitative Experiments.—Just as we can determine the threshold of intensity for vision, hearing, pressure, so we can determine the threshold for taste. This varies considerably for different individuals, and also for the four gustatory qualities. Bitter, sweet, salt, and sour have each their own intensity threshold. The method of determining this is as follows: Let us take for illustration the determination of the threshold for salt. Weigh out 10 grm. of salt and dissolve in a litre of water. Every cubic centimetre of this will then contain ·01 gr. of salt. Measure out 10 c.c. of this solution and make it up to 100 c.c. Each cubic centimetre of this will contain ·001 gr. of salt. Following this method we can make up salt solutions of varying strength, as, for example, of ·001, ·002, ·003 . . . ·01, ·02, ·03, etc., grammes of salt per cubic centimetre. Determine that solution with which the salt taste can just be detected using a simple variation of the method of limits. We can determine the threshold with practically any degree of accuracy. If, for example, we find that it lies between ·02 and ·03, that is, if the subject can detect no salt in the former and can detect it in the latter, we can make up solutions of strengths ·021, ·022, ·023, etc., and proceed as before.[1]

The following results have been obtained for the thresholds of the different tastes:—[2]

[1] This method is suggested by Dell in *Gateways of Knowledge*, p. 71.
[2] Sanford, *Experimental Psychology*, p. 48, after Bailey and Nichols.

Taste.	Substance.	Dilution in Water.
bitter	quinine	1 : 390,000
salt	sodium chloride	1 : 2240
acid	sulphuric acid	1 : 2080
sweet	sugar	1 : 199

Smell.—The organ of smell, as we have already seen, is closely associated with the organs of taste. Smell also resembles taste in many ways. There are comparatively few pure odours, if we may so term the olfactory qualities, and the majority of our olfactory sensations are of a complex nature, frequently involving cutaneous and organic, in addition to gustatory sensations. It is a rather curious fact that we have no special names to designate special odours and to distinguish one odour from another, with the exception of the general affective terms "pleasant" and "unpleasant." We are content to discriminate odours by referring them to the sources or objects from which they come. We speak of the smell of onions, of a lily, of fish, and so on. It is, indeed, as if we were to call a colour "buttercup colour" in place of yellow.

The true organ of smell lies in the upper portion of the nasal cavity.[1] The olfactory region is supplied by two sets of nerve fibres. The respective functions of the two, however, are different. One has nothing to do with smell proper at all. When the fibres belonging to this set are stimulated we experience a tickling or irritating sensation. The other set serves the sense of smell. The stimulus for smell consists of very minute particles emanating from the odorous object. These particles are carried into the nostrils in breathing, and stimulate the olfactory hair cells. It has been generally held that these particles must reach the mucous membrane in which the olfactory cells lie in a gaseous form. Thus Weber filled the nostrils with water, and under these circumstances was unable to experience any sensation of smell. Arensohn, however, in a very careful investigation of this point, showed that if a weak salt solution was substituted for the water odours were readily perceived. Further, it has been shown that fishes possess a chemical sense acting at a distance—that is a sense of smell—since they are attracted

[1] See Appendix A.

to bait placed in water too deep for light to penetrate. And a well-known experiment of Bethe's led to a similar conclusion as regards crabs. Besides the olfactory membrane in man is constantly bathed in the fluid mucus. Hence W. S. Hunter was led to suggest that the stimulus in smell may, after all, be liquid in form, and that smell and taste differ only in degree of sensitivity.[1] The difference in sensitivity is, indeed, enormous. It has been estimated that smell is 24,000 times more sensitive than taste.[2]

As in the case of all sensations, the only direct knowledge we can obtain of olfactory sensations is from introspective examination of our olfactory experience, and introspective examination is, in this case, particularly difficult. It was found possible to analyse our taste sensations into four simple elementary tastes, but the elementary qualities of smell have presented much greater difficulty. Certain phenomena of smell, however, which lend themselves to experimental investigation, and which we will describe presently, have enabled us to arrive at some sort of classification of smells.

The first satisfactory analysis and classification of smells was due to Zwaardemaker, the eminent Dutch physiologist. He classified smells into nine classes, postulating nine systems of hair cells in the olfactory region, arranged in spatial order and corresponding to these nine classes. Zwaardemaker's classification was as follows :—

1. Ethereal smells—all odours of fruit, beeswax, etc.
2. Aromatic smells—camphor, lemon, rose, etc.
3. Fragrant smells—orange blossom, vanilla.
4. Ambrosiac smells—amber, musk, etc.
5. Alliaceous smells—assafœtida, fishy smells, etc.
6. Burning smells—toast, benzol, tobacco smoke.
7. Hircine smells—cheese, sweat, etc.
8. Virulent smells—all narcotic smells.
9. Nauseating smells—all putrefying bodies.

Although there were many difficulties in the way of accepting Zwaardemaker's whole theory, this classification of smell sensations was generally accepted until comparatively recently.

[1] *General Psychology*, p. 228. [2] *Ibid.*, p. 228.

It was felt, however, that further analysis was necessary, and that some of Zwaardemaker's elementary smells were still complex. The whole field was worked over again by Henning, with the result that the elementary smells were reduced to six, and, if Henning is right, these six are related to each other in a very definite way, which can be represented schematically by a figure not unlike the colour pyramid. Henning's six elementary smells are: (1) Fruity (e.g. lemon); (2) Resinous (e.g. resins); (3) Flowery (e.g. violets); (4) Spicy (e.g. nutmeg); (5) Burning (e.g. tar); and (6) Putrid (e.g. decaying matter). If these smells are schematically represented by a triangular prism, with flowery, fruity, and foul at one end, and opposite them at the other end spicy, resinous, and burning respectively, the lines joining each pair will give us intermediate odours between the two, and the whole will represent with fair adequacy our world of smell.

It must be carefully noted that some so-called smells are not really odours at all. Curious though it may seem, ammonia is a practically odourless fluid. Its pungency is, in the main, due to peculiar tactual sensations, the particles emanating from it setting up an irritation, which stimulates the first set of nerve fibres already mentioned, and which is accompanied by sensations of an organic nature due to reflexes which are evoked.

As in all sensory departments, great individual differences exist with respect to the sense of smell. There are some people who seem entirely devoid of a sense of smell; there are others who are incapable of perceiving certain smells. The phenomena are analogous to total and partial colour-blindness. We may speak, therefore, of total and partial anosmia, either congenital or acquired. Many people, for example, are unable to smell the odour of prussic acid: others are unable to smell benzoin or vanilla; for others mignonette has no smell, nor have violets. This fact, in itself, would seem to indicate differentiation of function in the olfactory cells. In the case of total anosmia the sensations of touch, taste, and the characteristic pungency of ammonia may be present, all that is lacking being the olfactory sensation. It is possible to produce anosmia either total or partial by artificial means. Certain substances affect our sensitivity to certain smells, leaving others unimpaired.

This last fact has proved very useful in the analysis of complex smells. "A subject whose organ is fatigued by the continuous smelling of tincture of iodine can sense ethereal oils almost or quite as well as ever, oils of lemon and cloves but

faintly, and common alcohol not at all."[1] If an olfactory sensation is due to the compounding of two elements, and the subject has been rendered anosmic to one of them, the other is at once distinguishable. Now, our sense of smell is very easily fatigued. If we inhale the fragrance of a flower steadily for about a minute we shall find that the odour diminishes in intensity very rapidly, and finally the flower becomes quite odourless. So in the case of tincture of iodine in the experiment just cited. But it is not a case of fatiguing the organ of smell as a whole. Some odours remain unaffected. From this we can infer that only a part—say some cells—of the organ of smell is affected by the tincture of iodine, and no odour belonging to the same group, that is, affecting the same cells, can be smelt until recovery has taken place. Much experimental work has been done in this field, and, as we have already indicated, such classification of smells as have been made, are partly based on the results of such experimentation. Moreover, complementary information may be obtained by studying what may be called successive fatigue. Some odours, if smelt continuously, seem to undergo change. For example, oil of camphor smells first like turpentine, and this odour is replaced later by a smell like nutmeg. Hence we argue that the smell of oil of turpentine is complex, and comprises at least two component smells.

As a result of these fatigue experiments, and of other experiments which we shall describe presently, other facts and relationships with respect to odours have been worked out. Smells which are similar often emanate from substances the molecules of which have the same chemical build. Then again there is a long series of allied chemical substances, the smell of which gradually increases in intensity with increase in molecular weight. Thus marsh gas (CH_4), the first in the series, has practically no smell. Ethane (C_2H_6) has a faint odour, and the odour increases as we pass up the series, propane (C_3H_8), butane (C_4H_{10}), etc. Sir William Ramsay propounded an interesting theory based on this fact. He suggested that the intensity of an odour depends on the size of the molecules stimulating the hair cells. These molecules must of course emanate in a gaseous form from the substance, whether that be itself solid, liquid, or gas. Marsh gas has no odour because its molecules are too small. On the other hand, many substances yield similar odours, and

[1] E A. McGamble, *The Applicability of Weber's Law to Smell*, p. 7.

no resemblance in their chemical constitution can be traced. When sulphuric acid is mixed with water an odour like musk can be smelt. It is said that if emeralds, rubies, and pearls are ground for a long time, an odour like that of violets is given out. Puzzling facts like these make it very difficult to reach any satisfactory conclusion regarding the connection between odour and molecular structure. There are still other facts indicating some connection. In experiments at Edinburgh Kenneth found that some of his subjects described odours in musical terms, and when asked to arrange odours according to the olfactory analogue of pitch, arranged a group of allied chemical substances on this basis in an order which corresponded to their molecular weights. Other experimenters have obtained similar results.

In all smell experiments certain precautions must be observed. As far as possible the air in the room in which the experiment is being performed must be kept fresh and free from any odour. The breathing of the subject should be even and regular, and sniffing must be avoided, since it causes a reduction in the intensity, and an irregular reduction, by increasing the dilution with air of the odorous substance.

There are in the domain of smell phenomena of the same type as we have already discussed in the case of taste. We have two organs of smell one in each nostril. If we lead by means of an olfactometer—which will be described presently—one odour to one nostril and another odour to the other nostril, one of three things may happen. The odours may cancel one another—as a perfume cancels a disagreeable odour. This, as we have already seen, we call *compensation*. Or the two odours may combine to produce a new odour. Or there may be, not fusion, but alternation of the odours, that is, *rivalry*. The case of fusion is specially interesting, because the fusion must take place centrally, that is, in the cortical centre for smell.

Quantitative Experiments.—As in the case of the other sense departments, we can determine thresholds, both absolute and differential, for odours. This is really testing acuity for smell. Two methods are available. We may prepare a series of bottles each containing a solution of the substance we are going to use, in different degrees of dilution. This is precisely the same method as was described when we discussed quantitative taste experiments. Or we employ the olfactometer, a special piece of apparatus designed by Zwaardemaker for this purpose. This apparatus consists essentially of two glass tubes (the double

olfactometer) bent upwards at one end for insertion into the nostrils, and with a millimetre scale etched on them. The tubes are passed through two apertures in a metal sheet which serves as a screen. Over the straight ends of the tubes, which are thus hidden from the subject, are slipped hollow porous tubes containing the solution of the odorous substance. By drawing out this tube a larger area of it can be exposed to the current of air drawn into the nostrils through the inner tube, and the quantity of odorous particles proportionately increased. The scale enables us to read off the length of the outer tube so exposed, and the area varies as the length. If only one nostril is being used in any experiment only one tube is used.

If in determining the absolute threshold for any odour an olfactometer is being used, the subject will perceive no odour at all to begin with. The hollow tube is gradually moved out until the odour becomes perceptible. It should be noted that the odour may be perceived long before it can be identified, even in the case of familiar odours. The threshold for smell varies considerably for different odours and also for different individuals. With musk, for example, the threshold is very low. It is well-known that the odour of a grain of musk may be felt for years. The intensity of an odour also depends on the extent of surface stimulated. The larger the area stimulated the greater is the number of particles smelt, and the more intense, therefore, the sensation.

Tastes and smells are accompanied to a marked extent by agreeable or disagreeable feelings, and our main interest in them is with reference to their affective colouring, rather than with reference to the knowledge they convey. For this reason the investigation of taste and smell has been, to a large extent, neglected. It is true that these sensations do not rank so high with man as do vision and hearing, for they do not yield the same accurate and detailed knowledge of the outer world. As man has advanced in development and in civilization, the sense of smell has apparently degenerated. With some of the animals, however, smell plays a very important part in life, sometimes a more important part than is played by sound or sight. It is difficult for us to realize what a dog's sense of smell means to it, or to understand how it is guided more by smell than by sight. Possibly the smell of the human being might still be greatly developed. Under present conditions, however, such development would be far from advantageous.

CHAPTER V

SENSATIONS OF MOVEMENT AND OTHER ORGANIC SENSATIONS

SHERRINGTON has classified the various stimulus receptors or sense-organs into three groups on the basis of their position. The three groups are those of the exteroceptors, the interoceptors, and the proprioceptors respectively. The first are situated in or near the external surface of the body, and are excited by stimuli from the external environment; the second are situated on the internal surface of the body—mouth, alimentary canal, etc., and are excited by stimuli from objects coming in contact with that surface; the third are situated within the tissues of the body, and are stimulated by changing conditions in these tissues. Of the proprioceptors those giving rise to sensations of movement are of greatest interest to the experimental psychologist. These sensations are frequently grouped under the heading of the muscular, motor, or kinæsthetic sense, and play a very important part in the development of the individual's knowledge and skill.

Motor or kinæsthetic sensations inform us regarding the position of the body, and the movements and mutual relations of the limbs. The joints of the body are moved by muscles which are connected to the bones by means of tendons or sinews. Kinæsthetic sensations are derived from muscle, tendon, and joint itself. There is some controversy with respect to the specific end-organs, but that there are sensory end-organs—the muscle "spindles"—in muscle and tendon may be taken as definitely established. There are apparently also tactile end-organs in the joints, on those surfaces which move over one another, but there is some doubt with respect to the identification of these, and also with respect to the part they play.

When we move finger, or elbow, or foot, we experience a kinæsthetic sensation, or rather a series of kinæsthetic sensations, which inform us regarding the position to which the part in

question has been moved. It may be objected that we know our arm is in a certain position by seeing it there. Of course, this is quite true. Vision does enable us to correctly localize the limbs in space. But, if we close our eyes and actively move the arm, or, better still, get someone else to move it (this is known as *passive* movcment) we can still tell with considerable exactness the position it is in. In this case we are relying on our sensations from joint, tendon, and muscle, and to a slighter degree on our sensations from the overlying cutaneous surface. As a matter of fact the kinæsthetic sensations very rarely occur alone. They are closely associated with our visual sensations, and they are almost always complicated with cutaneous sensations due to the stretching and relaxing of the skin, and also with other tactual sensations due to the contact of cutaneous surfaces. It has been shown that if the skin is rendered insensitive, as by the application of cocaine, the kinæsthetic sensations are practically unaffected, and the position of the anæsthetic limb can still be accurately indicated. Hence the part played by cutaneous sensations in our accuracy of localization of the position of the limb must be regarded as relatively unimportant.

In addition to telling us of the movement and position of our limbs, kinæsthetic sensations also give us the sensory basis of our judgments of weight, and to some extent pressure. In the matter of pressure, the pressure sensations in the sphere of deep sensibility contribute largely, but if weights are lifted the kinæsthetic sensations play the chief part in making our judgments accurate. We judge the weight of an object by the amount of strain we experience, and also by the effort we put forth. We shall require to consider both more fully later. In the meantime it is sufficient to say that sensations of movement and sensations of strain are really different in modality, though both are included under the head of kinæsthetic sensations. In sensations of movement the muscle probably plays the least important part; the feeling of strain, on the other hand, arises in the muscles and tendons. As for the feeling of effort, that is partly due to the resistance against external pressure or tension. As regards our apprehension of the position and movement of the limbs, sensations arising in the joints appear to possess most significance. Other sensations also included under motor sensations are the sensation of cramp in the muscles, and the complex of sensations in muscle, tendon, and joint, which we describe as fatigue.

The part played by the various types of end-organ and the sensations they yield, in our experience and estimation of the direction, speed, and extent of movement, is not very clear. By various methods of producing partial or local anæsthesia we can cut out different groups of sensations. Thus, by making the skin over a joint anæsthetic, we can eliminate the part played by cutaneous sensations in our experience of movement at that joint. By passing a faradic current through the joint we can presumably eliminate the influence of the sensations in the joint itself. Certain nervous diseases also have the effect of eliminating some groups of sensation, and leaving others intact. All the evidence obtainable from the various sources points to the view that sensations of movement are mainly resident in the joints. Anæsthesia of the skin over a joint does not impair in the least degree the acuity of the sense of movement at that joint, whereas anæsthesia of the sense-organs within the joint impairs acuity very markedly. This last fact—for the sense-organs in the muscles are unaffected—would seem to indicate that the part played in our experience of movement by sensations from the muscles themselves is by no means so significant as we are apt at first sight to suppose. This conclusion is confirmed by the fact that in jointless organs composed of muscle there is a very imperfect appreciation of movements and position. As we have already indicated, the sensations received from the muscles themselves are sensations of strain rather than of movement.

Experimental work on kinæsthetic sensations falls into three divisions: the study of movement of the limbs, and of the conditions determining estimation of extent of movement; the study of weight estimation, particularly by lifting weights; and the study of the phenomena produced by rotation or tilting of the body. We shall require to consider each of these in turn, beginning with the first.

Study of Movement.—A very simple experiment will make us conscious of kinæsthetic sensations, strictly so-called, and of the function they perform in guiding movement. Sit in front of a table with eyes closed, with the two hands resting together on the edge of the table in the median line of the body, and with a small cork held in either hand—say, the right. Now move the right hand away from the left in any direction over the surface of the table, but without touching it. Lay down the cork at any spot on the table, and then move the right hand back to

its previous position beside the left. Let two seconds elapse, and then try with one movement of the right hand to pick up the cork, noting particularly the sensations by which the movement of the hand is guided. There are of course also kinæsthetic images, and possibly—nay probably—visual images as well, co-operating in the guidance of the hand. The experiment may be repeated with the left hand.

Our estimate of the extent of movement of a limb depends on various factors. Some of these factors can be isolated and studied without the employment of any very elaborate apparatus. Place two rulers end to end along the edge of a table, about an inch from the edge. Let the subject sit facing the edge squarely, with the junction of the rulers in the median line of the body, and let him place the forefingers of the two hands together at this point. Two or three simple experiments may now be carried out. In the first, when the experimenter says the word "now," the subject, with closed eyes, begins to move the two forefingers simultaneously outwards, and so in opposite directions, trying to keep the distance moved through the same for both. The experimenter puts down his pencil in front, sometimes of the right hand, sometimes of the left, to act as a stop, and the distances moved by the fingers are then read off on the rulers. In most cases the distances traversed by the two hands will be found to be unequal. As a rule the right hand will have moved through the greater distance in right-handed subjects, the left in left-handed—that is, the preferred hand in both cases. If the fingers are moved successively, as may be done in a second experiment, the same results will probably be obtained, but in this case the effect of preference may be masked by the influence of the rate of movement of one or other of the hands. It is always essential that the subject should be kept ignorant, during the experiment, of the results he is giving. Otherwise he may set himself to correct for the errors he is making, and, through over-correction, give precisely the opposite results. This tendency to over-correct for a known error is a very common complicating factor in psychological experiments. It is specially marked in the case of kinæsthesis because of the fact that turning attention to a movement causes its extent to be over-estimated.

The defects of this simple method of experiment are fairly obvious, when we employ it with the view of obtaining exact quantitative results. It is clear that there is no means by which

we can secure that the share taken in the arm movement by the respective joints, and by the respective groups of muscles, will always be constant from experiment to experiment, or even in the same experiment. Nor is it easy to secure constancy in the rate of movement. Myers[1] gives a drawing of a somewhat more elaborate apparatus, which may be employed for these and similar experiments, but it is more or less liable to the same defects.

Estimation of Weight.—Experiments on the estimation of lifted weights, as we have already seen, have played a very important part historically in the development of experimental psychology. Such experiments are still regarded by most laboratory psychologists as of very high value for methodological reasons, though their practical value is not so great, perhaps, as that of many of the other experiments carried out in the psychological laboratory.

Our usual method of estimating the weight of an object is by lifting it and lowering it with the hand. It can easily be shown that this process involves far more complex factors and conditions than might be supposed. In the main our estimate Interpre-
of weight in such cases depends upon motor sensations. It is tation
true there are also sensations of pressure involved, but these are of relatively slight significance, as far as our estimate is concerned. The main factors upon which our estimate is ordinarily based are the sensations of tension in muscles and tendons. It is also influenced by the rate at which a weight is lifted. The fact that the influence of rate of movement in the determination of weight persists even when the eyes are closed, but disappears in the case of subjects suffering from locomotor ataxia, shows that its source is in the sensations from the sensory end-organs in the muscles and tendons.

The amount of effort put forth in lifting, and the ease with which, and the height to which, the object rises in consequence, influence our estimate of weight, especially of the comparative weight of two objects, in curious and interesting ways. The effort we put forth is normally guided by our visual perception of the object to be lifted. If, then, we have to lift two objects, one of which is much larger than the other, we put forth a greater muscular effort in lifting the larger, and a smaller effort in lifting the smaller. Consequently, we may find the larger

[1] See *Textbook of Experimental Psychology*, pt. ii., p. 33.

object unexpectedly light owing to the ease with which it is lifted, and the smaller object in an analogous way unexpectedly heavy. This is clearly illustrated by what is known as the *size-weight illusion*. If two objects of the same shape and weight, but one of which is double the size of the other, be presented to the subject in an experiment in estimating and comparing weights, he estimates the larger as much the lighter. So persistent is the illusion, that even when he has seen the two objects weighed, and knows them to be equal, he still feels the larger to be the lighter. The illusion persists, even when the eyes are closed, if tactual sensation enables the subject still to apprehend the size of the one object as compared with the size of the other. If, however, measures be taken to prevent any apprehension, visual or tactual, of a difference in size, there is no illusion. The amount of the illusion can be readily determined. That is to say, we can determine what larger weight the subject estimates as equal to a smaller weight, say, of 500 grms., and the difference gives us a measure of the illusion. The amount of the illusion is found to vary considerably with different individuals. It is also greater with adults than with children; in fact, it is said to be absent, or even reversed, with very young children.

Motor Attunement.—The phenomena of what is called "motor attunement" are of the same order as those of the size-weight illusion. If we lift alternately two objects of the same appearance, but of markedly different weight, the one (say the heavier) with the right hand, the other (the lighter) with the left, after we have continued lifting for twenty or thirty times, different motor attunements are established in the two hands. When we now try to find a weight, which, lifted by the right hand, will be estimated as equal to another weight lifted by the left hand, we arrive at a judgment of equality when the weight lifted by the right hand is much heavier. It is evident that these phenomena are similar to those already discussed in the chapter on cutaneous sensations under the head of "accommodation."

We have already, in the Introduction, described a weight-lifting experiment in illustrating the Method of Right and Wrong Cases. The experiment there described is a typical quantitative experiment in this field, and is an experiment which finds a place in most laboratory courses in psychology on account of its methodological value.

Phenomena of Rotation.—The phenomena produced by rota-

ting or tilting the body are again strictly phenomena in a different sense department—what we might call the *static sense.* They are, however, so closely allied to the phenomena we have been considering that static sensations may fittingly be included under kinæsthetic—at least as fittingly as sensations of strain or tension.

The end-organs for the static sense are situated in the inner ear. The three little semi-circular canals in each ear, which we alluded to in discussing hearing, are the end-organs for sensory stimuli whose function is the maintenance of bodily equilibrium. The three canals are at right angles to each other, one lying in the horizontal plane, the other two in vertical planes. They may be said to lie in the planes in which confusion may readily take place. We may confuse up and down, back and front, left and right. The slightest movement of the body causes a movement of the fluid with which the canals are filled, and this movement in turn stimulates the hair cells, the hairs of which are immersed in the fluid. James compares these six little canals to spirit levels, from which we derive all our sensations of tilting or rotation of the head, and which, unconscious though we may be of their assistance, continually aid us in preserving our balance. Animals deprived of their semi-circular canals are unable to maintain their equilibrium, or to co-ordinate their movements. Deaf people, whose semi-circular canals have been seriously affected, are unable to maintain their balance when blindfolded. The canals are also responsible for the sensation-complex of giddiness or, as it is familiarly called, "swimming in the head."

As we have indicated, the semi-circular canals are stimulated by movements of the head, or rather, by any change from rest to movement, any change in rate or direction of movement, or any change from uniform movement to rest. The phenomena following on such stimulation are ordinarily studied by rotating the subject on a turn-table. When an individual is rotated with closed eyes, provided the rotation is at a constant rate, and the plane of rotation is maintained constant, he very soon loses all consciousness of movement. If he moves his head, or if the rate of rotation is accelerated, consciousness of rotation returns. If the rate of rotation is diminished he has the illusion of rotation in the opposite direction.

When the subject keeps his eyes open during rotation, jerky movements of the eyes take place. The technical term for such

movements is *nystagmus*. At the beginning of rotation the eyes fixate a stationary object, then jerk forwards to another object, fixating that, and so on. While this stage lasts external objects appear stationary. Another stage, however, soon supervenes. The eyes remain passive following the movement of the body. External objects now seem to be moving in the direction opposite to that of rotation. This stage continues while rotation continues. When the rotation ceases a third stage is entered upon. The eyes continue to move forwards continuing the movement they had during rotation, then jerk suddenly back, then move forward again—nystagmus once more—so that external objects seem to continue moving for some time in the same direction as before.

Nystagmus has been demonstrated by an arrangement due to Dodge,[1] even when the eyes are closed. It is also shown when the eyes are reopened after rotation has stopped, although the eyes were closed during rotation, provided the rate of rotation is sufficiently high. These eye-movements must therefore be regarded as a reflex response to the stimulation of the semi-circular canals by rotation. The sensation-complex we call giddiness is also produced by rotation, and may be very intense and very disagreeable if the eyes are kept open. Giddiness, according to Myers, is due to "a discrepancy or confusion between the various labyrinthine, retinal, cutaneous, and motor sensations, which inform us of the position of the body relatively to the external world."[2] It may, therefore, be produced in various ways. Any sudden alteration of the visual field, while the body is stationary, any unfamiliar strain on the eyes, rapid stimulation of the eyes as with flicker, as also the influence of various drugs, acting on the central nervous system, will produce the sensation-complex. It is of some interest to note that the rotation of the environment about a subject who remains stationary will produce practically the same phenomena as rotation of the subject with stationary environment. In this case there is presumably indirect stimulation of the semi-circular canals through vision, and possibly all visual after-sensations of movement ought to be regarded in this way. However that may be, it is difficult to conceive of giddiness at least being produced without the semi-circular canals being affected.

[1] *Journ. of Experimental Psychology*, vol. iv., p. 165.
[2] *Text-book of Experimental Psychology*, chap. v., p. 64, pt. i.

Quantitative work on labyrinthine sensations may be done either with the turn-table, or with a tilting-board, by means of which the whole body is tilted in a vertical plane. The procedure is in no respect different from that adopted for quantitative experimentation in general. The threshold for both rate and extent of rotation, or of tilting, may be thus determined.

Visceral Sensations.—There is still an important group of sensations to be mentioned, though little more than mention is possible, since the experimental work done on these sensations has been very scanty. That is the group of sensations to which the designation *organic* is most frequently applied, but which might more fittingly be designated *visceral*, the term *organic* including kinæsthetic and labyrinthine sensations as well, together with pain and deep sensibility. Visceral sensations play no mean part in our experience as a whole, for they determine to a large extent, or at least underlie, our complex moods. The general feeling " tone " of the body—the *cœnæsthesia*—the feeling well, or the feeling of vague general discomfort, is largely due to these visceral sensations. We do not discriminate them in normal health, but they form, as it were, a vague extensive background, on which our experience as a whole might be said to be projected. Sometimes one group of visceral sensations becomes more prominent than the others, and this is always to a marked degree accompanied by a definite feeling of pleasure or the reverse. To such an extent is this the case, that some psychologists have sought to identify pleasure and unpleasure with vague and rudimentary visceral sensations. In any case visceral sensations are bound up with the vegetative and nutritive life of the organism and, as we should expect, therefore are markedly tinged with " affect."

The whole class of visceral sensations has much in common with cutaneous. Any grouping that is possible can scarcely be claimed as qualitative, but depends rather on location in the body. Thus there are sensations associated with the alimentary canal, with the respiratory system, with the heart, and so on. There are, however, characteristic sensation-complexes. For example, the " closeness " of a room would seem to be due to sensations developed mainly in the respiratory apparatus. But it has a very characteristic quality. In the same way the drying of the membrane at the back of the throat, at the entrance to the alimentary canal, gives rise to the experience we call " thirst " ; the sensory experience in nausea is produced

in the region of the æsophagus, and is also a characteristic complex of sensations ; and hunger is a complex experience, due, so far as it is sensory, to muscular contractions of the stomach.

As we shall see later, visceral sensations accompany all intense emotions, such as intense fear or anger, and some psychologists have identified these sensations with the emotions themselves as experiences. It is beyond question that the circulatory and respiratory systems, and frequently the digestive system as well, in moments of strong emotional excitement, make a large contribution to our general experience at the time. This contribution we must consider from another point of view when we come to discuss feeling and emotion.

CHAPTER VI

PERCEPTION

THE psychology of perception was more or less central in that traditional psychology which was really metaphysics rather than positive science, which at least passed over into a theory of knowledge or epistemology in such a way that no one could say where psychology ended and epistemology began. Most of the philosophical speculation of modern times, at all events since Hume, has centred round the theories of perception, and psychology has been freely called upon to support contradictory views by opposing schools of philosophy. In these theories of perception, however, experimental psychology has had little share, and until recent times, except for work on space and time perception, little experimental work had been done in this field. Recently a school of German psychologists, generally known as the *Gestalt*-psychologists, has initiated an experimental study of perception which bids fair to revolutionize the psychology of perception, and which has already placed in an entirely new light some of the results previously obtained in special fields, as, for example, in the study of the optical illusions.

Perception is the immediate apprehension of an object or situation affecting any or all of the sense-organs by way of sensation. It is the most elementary form of cognition, and indeed of experience. Much of the difficulty and controversy regarding perception has arisen because sensation has been looked upon as the most elementary mental process. This is not the place to discuss the question, but it may be pointed out that sensation is merely an aspect, never the whole, of experience, and that bare sensation does not exist in the concrete. Among the lines of evidence for this statement might be cited the results of the *Gestalt*-psychologists. As against the view that a percept is nothing more than a group of sensations—the "bundle

hypothesis"—the evidence brought forward by the *Gestalt*-psychologists must be regarded as quite conclusive. They have also performed highly useful service in the direction of showing how, and in what sense, perception is always perception of a single object, that is, of a whole. Some of their experiments are of the simplest kind. Take, for example, the "fence phenomenon." Fig. 5 shows eight lines, *a*, *a*, *b*, *b*, *c*, *c*, *d*, *d*, so drawn that the distance between *a* and *a*, *b* and *b*, etc., is less than the distance between *a* and *b*, etc. Sensationally, we should get merely eight lines in pairs, with the spaces between them simply parts of the white page, and differing from one

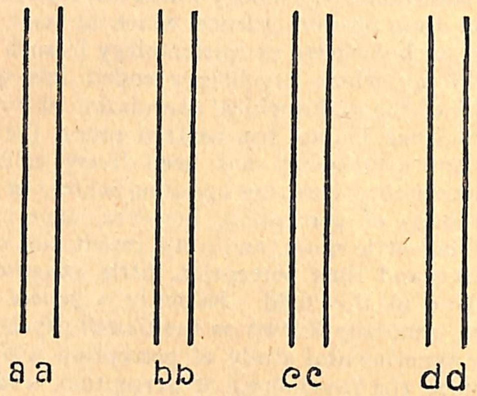


FIG. 5.

another merely in width, as the distance between *a* and *a* is less than the distance between *a* and *b*. What we actually get is a figure composed of the eight lines in pairs, *with the spaces between* the lines of *each pair*, on a background formed by the rest of the page. That is to say, the spaces *aa*, etc., form part of the figure, while the spaces *ab*, etc., form part of the background. The white spaces forming part of the figure do not differ sensationally from the others, yet they unmistakably differ for our perceptual experience. These spaces, as perceived, do not extend beyond the bounding black lines, and do not form part of the surrounding white space, but are definitely marked off from it—some observers can in fact describe curves marking them off, which have no objective existence. The essential point, however, is

that for perception we have "figure" and "ground," and this holds in all sense departments.

The phenomena may be described in terms of the older analytic psychology, always with the proviso that what is distinguishable does not necessarily exist as separate. In every perceptual experience of the adult human being we can distinguish three groups of factors, which may be designated *presentative*, *representative*, and *relational* respectively. The actual sense data at the moment we are designating the presentative factors. Representative factors are factors involving the revival in some form of past sense experience of the same or similar situations or objects. These factors may be regarded as merely additions of the same order to the presented sense data, additions which are not actually presented but reproduced as a result of past experience. In our perceptual experience of an object sensations derived from the object through different sense organs, according to the older view, tend to connect themselves together by a process which has been called *complication*. The result is that in subsequent perceptual experience of that object the particular sense datum of the moment tends to be accompanied, or qualified, by the other sensations formerly experienced. This usually takes the form of a vague psychic fringe, but it is possible to regard some of the phenomena of *synæsthesia* in this way. Thus the whiteness of the sugar, which is at the moment affecting us through vision, is qualified by a sweetness which we do not see, whereas the whiteness of snow would be qualified similarly by a coldness, and the yellow of an orange would, as it were, drag into consciousness a fringe of sweet sensations, acid sensations, weight sensations, and so on. The facts are beyond dispute, though the older associationist explanation of these facts leaves much unexplained. The process is one of integration rather than of mere association.

It is with the relational factors, however, that we are more particularly concerned. These are factors determined by the relation of the object perceived to its sensory, ideational, and affective context. At present we have to deal in the main with relational factors which are of the purely perceptual order, though the general lines of our discussion will apply throughout. Perceptual experience in the human being, whatever may be the case with organisms low down the scale of life, is never separate and detached in the concrete, nor is any object or situation experienced in isolation. The experience of any one

moment is a whole in which certain elements, as it were, stand out. The experience of the next moment does not emerge as an entirely new experience, but comes as a change in that of the previous moment. Consequently, every object or situation apprehended is apprehended in relation to the whole experience of the moment, and to the experience of immediately preceding moments. This is the general and fundamental fact. It is emphatically a *situation* that we apprehend, and every element

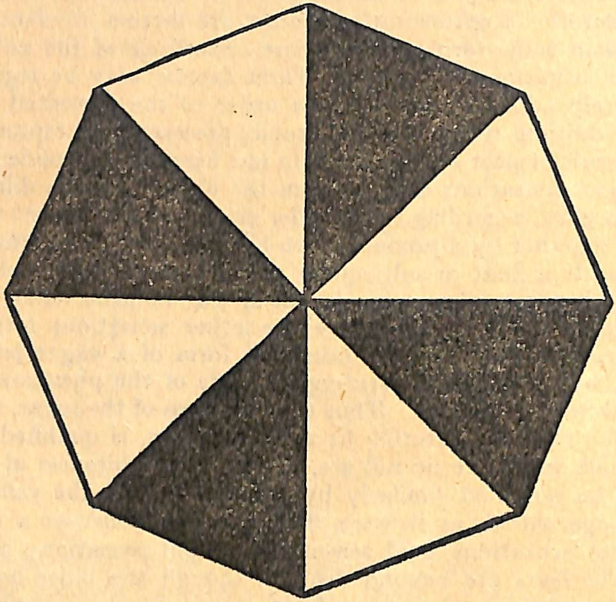


FIG. 6.

in that situation, which is momentarily separated out by the selective functioning of attention, is never thereby isolated, but is apprehended in a *setting*, that is, a *context*, while the situation itself is similarly apprehended in a context stretching back, even for perception, into the immediate past. Thus, from another point of view, we see that there is always this relation of " figure " and " ground " in perceptual experience, and that it is a necessary characteristic of perceptual experience.

Other experiments upon which the *Gestalt*-psychologists lay stress will illustrate this, as well as their own, position, and will

at the same time lead over to the consideration of the geometrical optical illusions, where the phenomena become most strikingly manifest. Let us take an experiment of Wertheimer's. If two lines, making an acute angle with one another, are exposed successively by means of a suitable tachistoscope, with an appropriate interval of time between the appearance of the first and that of the second line, what the subject sees is one line, which seems to move from the position of the first to the position of the second. Similar phenomena appear if we expose two points in place of two lines. In this case we can produce the appearance of two points appearing one after the other, or of one point moving in the field of vision, or of two points simultaneously present, according to the time interval. This illusion of movement is illustrated on a large scale by the cinema.

Take now a case of an equivocal or ambiguous figure, such as that shown in Fig. 6. Here we have either a white cross on a black background or a black cross on a white background. We shall have more to say of such figures presently. In the meantime what we are interested in is the real nature and extent of the change that takes place when the black cross gives place to the white cross. When we see the black cross we see it on a white background which gives no suggestion whatever of a cross, but which rather gives the suggestion of being continued behind the black cross and of being more or less circular in shape, though its shape is somewhat vague. When the white cross becomes the figure the black cross similarly entirely disappears as a cross, and becomes a black, vaguely circular background. In each case figure stands out from background as if in a different plane.

The Geometrical Optical Illusions.—An illusion may be defined as " a subjective perversion of the objective content of sense perception." From what has just been said it will be obvious that there is always, in perception, something that may be described as a " subjective perversion." There is always at least a subjective addition to the sensational content. In the real illusion, however, there is a discrepancy between what is perceived and the real object. In the case of the geometrical optical illusions we take the real object as the object which is actually present according to the verdict of the scientific, mathematical, or measuring eye, the object apparently seen differing from this in some way. A perfect square mathematically, for example, always looks higher than its breadth.

These illusions may be classified into three main groups: (*a*) illusions of ambiguous or reversible perspective; (*b*) illusions of extent or distance; and (*c*) illusions of direction. All three groups are interesting from the point of view of the *Gestalt*-psychologists, as well as for the light which a study of the phenomena throws on the part played by more or less obscure psychological factors in our space perception.

(*a*) *Illusions of Reversible Perspective.*—In order to obtain

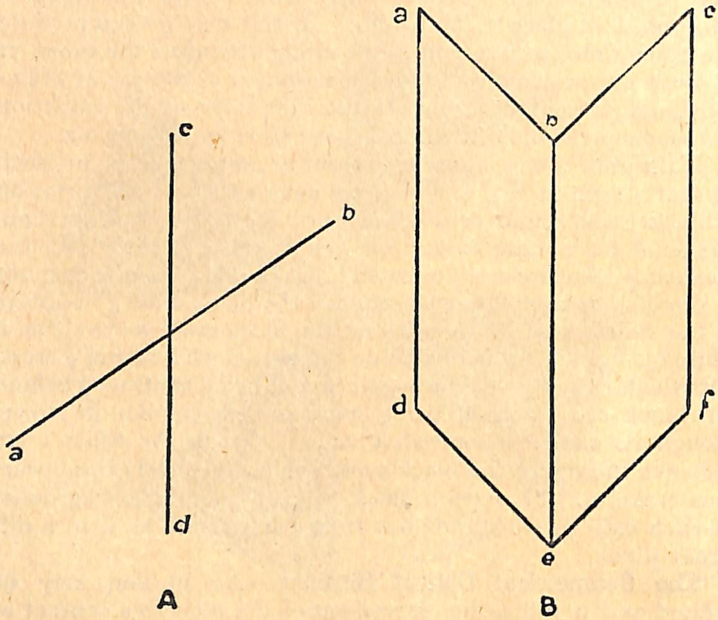
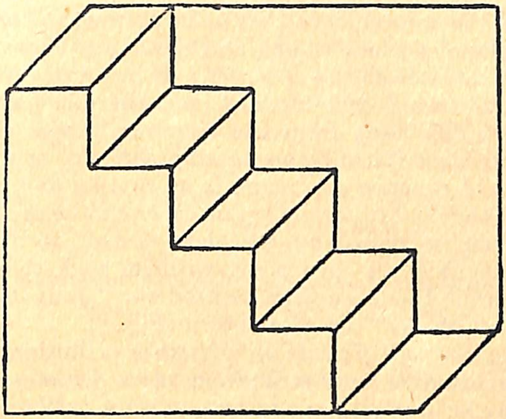


FIG. 7.

the illusion effect most clearly the figures should be drawn in white on a black background. Reversible perspective figures are figures which show no perspective, and which therefore can be seen in either of two ways, so that at one time one part of the figure comes forward towards the observer, at another time the opposite part or side. The effect is very striking with some of the more complex figures, like Schröder's "stair figure" or Scripture's "blocks." But the effect can be obtained with quite simple figures like those shown in Fig. 7. If the subject



Schröder's "Stair figure."

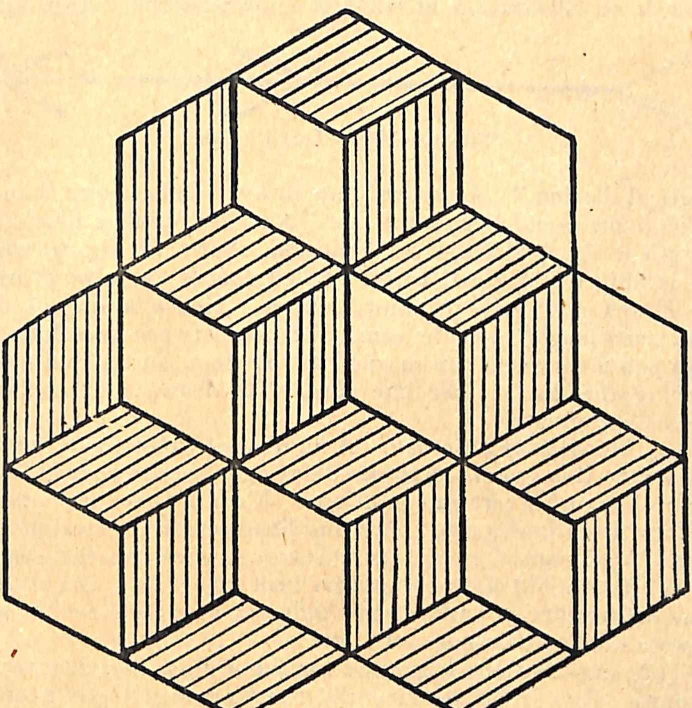


FIG. 8.—Scripture's "Blocks."

fixates *a* in the cross A, then that point appears to come forward from the plane in which *cd* lies, and the line *ab* appears to have a direction away from the observer. If he fixates *b* in place of *a*, then *b* in turn comes forward, and the line *ba* appears to have a direction away from the observer. Once the reversal has been obtained it can be produced practically at will, and the reader should practise producing it as rapidly as possible. In the case of the double parallelogram B, *bc* can be seen in a plane either in front of, or behind, the plane of *acdf*, so that we have the appearance of an open book, with its back either towards or away from the observer. Schröder's "stair figure" and Scripture's "blocks" are also shown (Fig. 8).

(*b*) *Illusions of Extent or Distance.*—Illusions involving under-estimation or over-estimation of a distance, extent, or length, may be produced in a variety of ways. We have already seen that a perfect square always seems higher than its breadth. This is an illustration of what is known as the "horizontal-

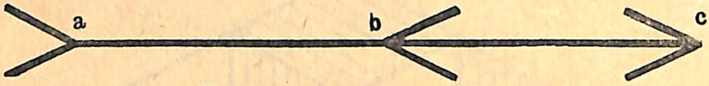


FIG. 9.—Müller-Lyer Illusion.

vertical illusion." A vertical line always seems longer than an objectively equal horizontal line. Another familiar illusion of length is the "Müller-Lyer" illusion, shown in Fig. 9, where *ab* is objectively equal to *bc*. Filled spaces are always over-estimated relatively to empty spaces. Hence a line of dots will seem longer than the same distance between two dots. If two equal distances are marked off by dots, and a line drawn joining the dots in the one case, that distance immediately seems the greater.

(*c*) *Illusions of Direction.*—A number of well-known illusions belong to this group. Straight lines may appear curved, bent, or broken under certain conditions. Each of these appearances is illustrated in Fig. 10. In A the lines across are straight and parallel, though they appear curved outwards at the centre; in B the straight line *acb* appears bent at *c*; in C the straight line *pq* appears as parts of two different straight lines, or as if *q* were not the continuation of *p*.

The explanations suggested for these illusions fall into two groups. One group we may call the "sensory" group of ex-

planations, the second the "relational" or "inference" group. Not that these latter involve the postulating of anything that can be called inference in a strict sense, but because they involve postulating subjective factors and subjective processes which suggest the higher levels of mentality rather than pure sense. According to the first type of explanation the nature of the

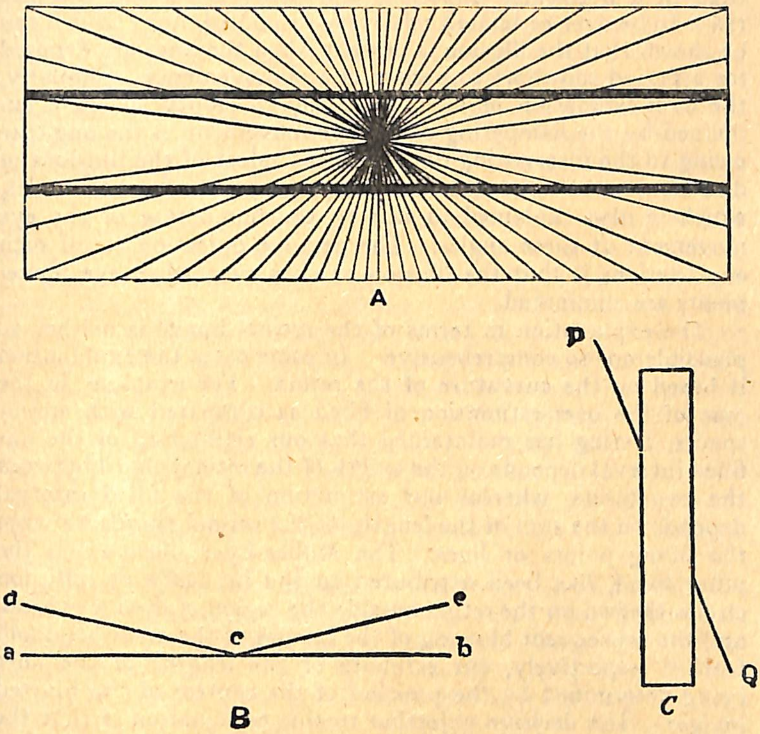


FIG. 10.—Illusions of Direction.

retinal image, or our experience of eye movements is accountable for most of the illusions. The latter is the more general explanation. In the case of reversible perspective it is claimed that the movements of the eyes towards a point in the figure, as, for example, towards *b* in Fig. 7 A, tends to bring that point forwards, and the whole figure adjusts itself accordingly. At a first glance this explanation seems satisfactory, especially since

most subjects find that they apparently do cause reversal of such figures in this way. It can, however, be shown that reversals sometimes take place without eye movement, and sometimes fail to take place with eye movement. In the same way the horizontal-vertical illusion is said to be due to the fact that greater effort is involved in moving the eyes in a vertical than in a horizontal direction, and hence a vertical distance tends to be over-estimated relatively to a horizontal. But it can be shown that the illusion is present when the lines are exposed for a period too short to permit of eye movements. Similarly, the over-estimation of filled relatively to empty spaces is explained by the hampering of the eye movement in the one case owing to the intervening dots or lines. Most of the illusions of direction are attributed to the over-estimation of acute angles, which is also explained as due to the hampering of the eye movement at these angles. The decisive objection to all such explanations is that the illusion persists even when eye movements are eliminated.

The explanation in terms of the retinal image is neither so plausible nor so comprehensive. In some cases the explanation is based on the curvature of the retina. For example, in the case of the over-estimation of filled as compared with empty spaces, Hering has maintained that our estimation of the unfilled interval depends on the length of the retinal chord between the two limits, whereas our estimation of the filled interval depends on the sum of the lengths of the retinal chords between the filling points or lines. The Müller-Lyer illusion, on the other hand, has been attributed to the influence of diffusion circles thrown on the retina outside the region of distinct vision, and the consequent blurring of the images of the arrowhead and feather respectively, our estimate of the lengths of the lines being determined by the position of the centres of the blurred images. The decisive objection to this explanation is that the illusion increases with the distance of the figure from the eye, that is, the more the image falls within the region of distinct vision, and the less the blurring.

The other type of explanation appears to be, on the whole, more satisfactory. Whether we adopt the views of the *Gestalt*-psychologists in their entirety or not, it is certain that there is a definite pattern in all the illusions, and that this pattern has a character and even activity an of its own. The suggestion of activity will itself explain some of the illusions. The suggestion

of perspective involved in some of the patterns will explain others. The fact that some of the illusions tend to disappear with practice, or with long fixation, would appear to support the relational or inference type of explanation.

Synæsthesia.—Synæsthesia means literally an accompanying or secondary sensation, but in general is used to designate concomitance of disparate sensations. The most frequent form which this phenomenon takes is the association of sound with colour. Coloured hearing, or *psycho-chromæsthesia*, as it has been called, occurs in many varieties, but in every case the auditory stimulus not only sets up its own appropriate stimulus, but at the same time is accompanied by a strong visual image which has become closely associated with it. These visual images are sometimes so vivid and intense that it is difficult to distinguish them from sensations. Music is closely associated in some individuals' minds with colour. No sooner do they hear a note than a colour flashes into their minds. Different instruments have each different colours associated with them, and specific colours may attach themselves to music of different composers—Grieg's music may be green, whereas Mendelssohn's may be brown. All types of music have a coloured background, and in some cases there may be a delicate but continual changing of colour as the theme develops. Not only may music be coloured, but voices of friends and acquaintances may have colour attached to them, and in extreme cases the synæsthesia may extend to persons in fiction or history and even to abstract qualities.

Vowels and consonants are frequently coloured, and so give to each word a corresponding hue. In some cases there exists a whole colour alphabet, with the letters changing in colour according to their sound. These are frequently in a definite spatial pattern. In addition, days of the week, months, and the seasons of the year may each have their characteristic colours attached to them. In one case met with lately, Monday is associated with pale pearly grey (sometimes silver), Tuesday with Prussian blue, Wednesday with light yellow, Thursday with brownish orange, Friday with bright bottle green, Saturday with pillar-box red, and Sunday with pale but brilliant gold.

The reverse associations may also occur but rarely, by which colours suggest letters. Galton [1] quotes the facts of one strongly

[1] *Enquiries into Human Faculty*, p. 110.

developed case. The individual could read various colours of wall-papers into different words and sounds, and conversely translated Galton's own name into different colours.

The associated light or colour is known as a photism, and in addition to these sound photisms, there also exist taste photisms, odour photisms, touch photisms, and pain photisms.

The following facts in regard to synæsthesia seem to have been conclusively established. Synæsthesia is hereditary, and children who have been found to be coloured thinkers, have usually sisters or brothers or parents who similarly think in colours. Dr. M. E. Bickersteth,[1] on testing over 2000 children, finds well-marked sex differences; girls at every age show more highly developed coloured associations than boys. She also claims that social differences appear, and that in schools where every child comes from an educated home the percentage of coloured thinkers is higher.

It is forty years since Galton drew attention to the characteristics of coloured thinking, and it was treated then, and is more or less still considered, as a phenomenon belonging to the region of abnormal psychology. This is a totally wrong view. The reason for the obscurity surrounding the whole question of coloured thinking may be traced, as one recent writer points out, to two causes. To those who are not *seers* (to use Galton's term for the coloured thinker) this phenomenon is quite meaningless, and one which does not call for any serious investigation. On the other hand, coloured thinkers seldom realize that there is anything unusual in their colour associations, and therefore seldom speak of them, and it is rare for the members of the same family to have a knowledge of each other's *psychochromes*, as they are called. Individuality is one of the distinctive characteristics of all synæsthesias: coloured thinking, as Galton points out, may be considered as an individual idiosyncrasy.

Synæsthesia, and in particular coloured hearing, is not a rare and exceptional phenomenon but is characteristic of many individuals. It is rare, however, to meet cases in which the series is complete and extensive. Rather, one individual may see only proper names coloured, a second the days of the week, a third the seasons, a fourth musical notes, and so on. Even when the same sounds are coloured, the colour scheme is not

[1] Unpublished Thesis on *Psychochromæsthesia*, University Library, Edinburgh.

necessarily the same for each individual, but the same colours are always used by the same individual, no matter what time elapses. Galton records a case where two years elapsed, and the second record communicated at the end of two years was exactly the same as the original report.

Explanations of synæsthesia have been offered from two points of view. The first forms the physiological theory " which regards an association between different brain centres as the basis of these pseudo-sensations." [1] The psychological theory, on the other hand, " regards synæsthesia as a persistent association, partly due to the peculiar idiosyncrasy of the individual, partly due to a predominant emotional tone." [1]

The cases of synæsthesia occurring in members of the same family seem to favour the physiological explanation, but there can be little definite proof of either theory.

Coloured associations can sometimes be traced to their source, as for example where children have learned the alphabet from some coloured sheet, and the fact that the alphabet often assumes the spatial form of a circle, supports this view, although this origin cannot be traced in every case. If this is so, such instances may be explained along the lines suggested in the preceding pages of this chapter as due to the process of complication. An auditory stimulus arouses not only its own appropriate sensation, but excites, in addition, some other sense department with which it has become closely associated. In other words, synæsthesia may be explained as caused by the working of the representative factor. It must not be thought that the associated colour or sound or whatever it may be, is of the nature of a psychic fringe. It is much more detailed and definite than that, but doubtless the same factors are involved in both cases. Whether all cases of synæsthesia can be explained along such lines is still to be proved, but where the definite source of association can be traced, such an explanation seems wholly to fit the facts.

Days of the week or months, etc., sometimes owe their colour to the colour of their initial letter. For example, Saturday may appear red because S is associated with red. Or the colour associated may be the individual's favourite colour, and it frequently makes an appearance. Dr. Bickersteth gives a very interesting explanation of coloured thinking in the Gaelic

[1] Baldwin's *Dictionary of Philosophy and Psychology.*

district of Scotland, where the percentage of coloured thinkers is very high. She traces, in many instances, the numerous colour associations to the use of colour terms in the Gaelic language. A gale of wind and rain is a "stoirm dhearg," a "red storm," and so the Gaelic child has the psychochrome "rain red." Dr. Bickersteth is further inclined to the view that environment has a strong influence on chromæsthesia. "To the Skye child, August has not the usual associations with yellow, but with grey or black, for August is the rainy month in Skye."

Number-Forms.—This is a phenomenon closely analogous to that of synæsthesia. In this case, whenever a number is heard, or even thought of, a visual image of the number appears in space. Such images vary in vividness, but in certain cases they are extremely distinct. Perhaps one or two figures may appear only, but again a whole number-form may flash before the mind. Galton writes: "Those who are able to visualize a numeral with a distinctness comparable to reality, and to behold it as if it were before the eyes, and not in some sort of dreamland, will define the direction in which it seems to lie, and the distance at which it appears to be." [1] Each number has its own definite position in space, and *in toto* they range from simple projections outwards to more elaborate arrangements of circles and curves. In some cases they can best be represented as tri-dimensional. The number-form is generally constant in shape and increases with increase in concepts, as, for example, extending in one particular direction to accommodate negative numbers. Sometimes the number-form is used for purposes of calculation, but whether it is always beneficial to its possessor is debatable. Galton reports one case in which the number-form appeared as a sliding rule which the owner could image very clearly, and by means of which he habitually worked out most complicated arithmetical calculations.

In some cases, the number-form is either coloured as a whole, or coloured in parts, or each individual letter may have a colour of its own. The numbers may even be given personalities. One of the characteristics of number-forms is that they flash into the mind whenever a number is mentioned. Another is that they have been in existence as far back as the individual concerned can remember. They are not a late acquisition, and rarely can any insight be gained as to their origin. But here

[1] P 79, *ibid.*

again, as in coloured thinking, occasional number-forms have been traced, either to methods of learning numbers or, perhaps, to the fact that certain positions in a street or locality have become definitely associated with a definite number-scheme, and now the numbers have become detached, as it were, from the place, and arrange themselves in a corresponding spatial pattern. But undoubtedly the tendency to possess number-forms seems to be hereditary and, in fact, though it has been reported but seldom, the same number-form may be transmitted from one generation to another. Galton compares such tendencies to the instincts of animals. He conceives that if a spider were to visualize numbers, it would do so in web-shaped fashion, whereas a bee would do it in hexagons.

The chief method used in the study of synæsthesia, including number-forms, is that of the questionnaire. A list of questions is drawn up such as: Do you think of letters as coloured in any way? or days of the week? or months? Do you think of numbers as arranged in any particular way? By having these answered by a large number of subjects definite quantitative and qualitative results can be obtained.

Space Perception

All objects perceived are perceived in perceptual space and time, or in a spatial and temporal order. In the meantime let us confine ourselves to the problems of space perception. In our perceptual experience of objects in the external world we apprehend these objects as of a certain shape and size, at a certain distance from one another and from us, in a certain direction from one another and from us. Let us suppose we are looking at some objects of the kind sometimes used as models in drawing lessons, say, a sphere, a triangular pyramid, a cube, and a square prism. They are situated in front of us about 10 feet away; the sphere is about 2 feet away from and to the left of the pyramid, the cube is beside, and to the right of the pyramid, the prism is in front of the line between the sphere and the pyramid, and rather nearer the former than the latter. Now we see, apparently at a glance, these solid objects, shaped as they are shaped, arranged in a concrete space in the way their arrangement has been described; position, direction, distance all apparently directly apprehended in our visual experience of the situation. Turn to the sense data. These are

visual sensations, and apparently the only immediate sense datum of a spatial kind is the attribute of extensity which visual sensations possess. Hence, in some way we must have *learned* to see spatial relations and spatial order. It is the business of the psychologist to show how this learning has taken place, and in doing so he has to rely to a very considerable extent on the results of experimental study.

Kinæsthetic sensations constitute the fundamental factor in the process of learning by which spatial order and spatial relations become definite. That is to say, sensations of movement define for us the relative positions of different points in that vague extensity, which is an attribute of cutaneous and visual sensations, as a result of which extensity becomes extension, figure and magnitude are clearly defined, and relative position, distance, direction, are all clearly perceived. But the question at once suggests itself: what makes the points, to which our sensations of movement, as it were, attach themselves, different in our experience? The character by which one point is distinguished from another in a sensitive surface is called "local sign," a name first given by the German psychologist Lotze. Apparently, then, the development of our space perception can be briefly and generally described thus: The spatial content of our experience is given in that attribute of sensation, which, in the case of cutaneous and visual sensations, we call extensity. Local signature marks off different points from one another. By means of movement the spatial relations of these points to one another become clear, and our spatial world is thereby defined.

The first problem for the experimentalist arises in connection with local signature. Must this character, by which one point is distinguished from another, be regarded as innate—what is called a *nativistic* factor—or is it a product of development—a *genetic* factor—in our space perception? It has been suggested that local signature is itself due to our experience of movement. The argument assumes its most cogent form in the case of vision. In that case there is a definite fixed point of clearest vision, the fovea. When an object stimulates any point in the marginal field there is a reflex tendency to move the eye so as to fixate the object, that is, so as to make its image fall on the fovea. Hence, it is said, the movement of the eyes necessary to bring an image from any point to the fovea will give a certain experience mark to that point, in other words, its local sign.

An attempt may be made to answer this contention on an experimental basis. If local signature originates in sensations of movement, then the sensitivity of an individual as regards eye movements ought to be of the same order as his discrimination of differences of position on the retina. We find that this is not so. The threshold for eye movement is high, the spatial threshold for the retina extraordinarily low. That is to say, considerable movements of the eye may take place without our being conscious of any movement, whereas a very slight distance between two points of the retina stimulated is at once recognized. The discrepancy is so great that it is inconceivable that retinal signature could have been developed from sensations of movement, unless the sensitivity to eye movements were immeasurably greater at the time when local signature was developed than it is now.

The experiment may be performed in various ways. There are really two separate points to be investigated. On the one hand, the *spatial threshold*, as it is called, for vision must be determined, that is, the smallest distance apart at which two points can be seen as two. It has been found that this distance is an angular distance of about one minute. The method of determining the spatial threshold for cutaneous surfaces will be presently described. There is no difference in principle with respect to vision except that points of light, dots, or lines are used in place of a pair of compasses. On the other hand, we must also determine the sensitivity of our subject with respect to movements of the eye. This is done in a dark room, the subject fixating a point of light. It has been found that the eyes can be moved through considerable angles without any consciousness of movement. We might have been prepared for such a result, since we have already seen that sensations of movement in the limbs depend mainly on sensations in the joints, not on sensations in the muscles themselves, and there are no joints involved in eye movements.

The Spatial Threshold.—When two blunt points of bone or vulcanite are applied simultaneously to the skin they may be apprehended as one point or as two points. The smallest distance apart at which they are apprehended as two points is, as we have said, the spatial threshold. It is also known as the *æsthesiometric index*, the determination being usually made with the instrument known as an *æsthesiometer*. Of æsthesiometers many different types exist, the simplest being a pair of compasses

provided with an arc of metal with a scale engraved on it. The spatial threshold varies between wide limits for different parts of the body. On the tip of the tongue a distance of 1 mm. is sufficient to give an experience of two points, whereas on the thigh the distance apart must be 68 mm. The procedure in determining the threshold may be by either the Method of Limits or the Method of Right and Wrong Cases. Care must be taken to place the two points down simultaneously and with equal pressure. If the Method of Limits is employed a start should be made with a distance at which the points are clearly distinguished. As the distance is diminished the subject will first experience two points separate, then two points apparently connected, then one elongated contact, and finally one clear point. The part of the cutaneous surface stimulated must, of course, be kept constant and also the line of direction of the points. Different thresholds are obtained, not only for different parts of the body, but also for the transverse and longitudinal directions respectively at one and the same place.

The spatial threshold or æsthesiometric index was at one time claimed as an excellent test for fatigue. There is no doubt that fatigue does tend to raise it, but the conditions are so complex that little confidence can be placed in the test. The mere difficulty of an accurate determination of the spatial threshold, and the fact that elaborate precautions are necessary to secure an approximation to reliability in the results obtained, would rule it out as a practical fatigue test.

If the application of the points to the skin is successive in place of simultaneous, there is a very considerable lowering of the threshold. Some experiments by Judd, the results of which were published in *Philosophische Studien*,[1] gave as the average threshold for five subjects 24 mm. with simultaneous stimulation, and 7 mm. with successive. The same experimenter also determined the smallest line distance that can be distinguished. With one subject a line was experienced when the length was about 12 mm., but the length had to be increased to 32 mm. before its direction could be clearly recognized. When the line was made by a moving point, a distance of 7 mm. sufficed for the motion to be appreciated.[2] All the results are of course relative to the part of the cutaneous surface stimulated.

[1] Vol. xii., 1896, p. 409.
[2] See Scripture, *The New Psychology*, p. 374 f.

All these results are obviously dependent on local signature, though the exact nature of local signs themselves remains obscure. Another kind of experimental investigation in the same field is the investigation of the absolute localization of a point on the skin. In this case the experimenter stimulates with a blunt rod some point on the skin, and the subject attempts with a similar rod to locate the point stimulated. There are several factors which influence localization under these conditions. If the forearm is being used for the experiment it will be found that there is a tendency to displace towards the margins, and also towards the wrist if the stimulus is given near the wrist, towards the elbow if near the elbow. There is also a tendency to displace towards any well-marked features in the landscape, so to speak, especially where visual imagery plays a prominent part in guiding the localization.

The Third Dimension.—The attribute of extensity, local signature, and movement sensations are adequate to explain our perception of spatial relations in a space of two dimensions. It is not clear, however, that they are adequate to explain our perception of depth or distance, that is, of the third dimension. Here, again, problems for experimental psychology have arisen. In the experience of the normal individual the perception of depth occurs mainly in the sphere of vision. The experience of the congenitally blind shows that it can also arise in the tactual sphere, but it remains true that for the normal individual vision is its main source. Moreover, it is binocular rather than monocular vision to which we are chiefly indebted for direct experience of the third dimension, though, as in the case of tactual experience, a certain measure of depth perception is possible for monocular vision. We may begin, therefore, by considering the perception of depth or distance in binocular vision.

When both eyes are used in vision we have obviously two retinal images, but under normal conditions perception of only one object. The two eyes, as it were, combine, and they function in the same way as a single eye would, if placed midway between them, provided both eyes are of equal value for vision, or of equal efficiency. If the two eyes are not of equal value the position of the "cyclopean" eye is shifted towards the stronger or better. The phenomena can be illustrated by a very simple experiment. Let the reader with both eyes open point at some object in the room, and then, keeping the finger

in the same position, close first one eye and then the other. With the right eye closed he will find he is pointing to the right of the object, with the left eye closed to the left, and if the two eyes are equal he is the same distance out in the two cases. If one eye is very much better than the other, he may find that he is still pointing right when the other eye is closed, but when that eye is closed he is pointing very much to the side of the closed eye. The object is localized with reference to the median eye, except in this last case, where it is localized with reference to the better eye.

The fusion of two images can be produced by means of the stereoscope when the images are received from two separate objects. With some little practice the fusion may be obtained without the assistance of the stereoscope. Fusion takes place in this case, as in the case when a single object is looked at with both eyes, when the two images fall on the retinæ in certain definite positions. In either retina there is a point corresponding to a point in the other retina, so that, if the two points are stimulated simultaneously, the two eyes function as one eye, and but one point is seen. Such points are called *corresponding* or *covering* points. The surface which contains all the corresponding points, or rather the source points from which rays fall on the corresponding points of the two retinæ in any given position of the eyes, is called the *horopter*. If rays of light fall on the retinæ from any source outside of the horopter for the then position of the eyes, they fall on points which are not corresponding, but *disparate*, and ought, theoretically, to give rise to double vision. Hence at any moment we ought to have double vision for all points outside of the horopter. Practically we do not, because the double vision is subjectively suppressed.

But it has been claimed, and experimentally it seems to be verified, that there may be slight disparation without any experience of double vision, suppressed or not, in which case we have a direct experience of depth or relief. In order to understand what happens in this case, it is necessary to consider a single point of fixation, and objects nearer or farther away than that point. If an object is either considerably nearer or considerably farther away than the fixation point, we have double vision of that object, owing to the fact that there is considerable disparation. But the two cases are different. In double vision one object is seen at each side of the fixation point. But if the double vision is of an object nearer than the

fixation point it is crossed, that is, the image seen to the right is that of the left eye, the image to the left that of the right eye; whereas, if the object is farther away than the fixation point, the double vision is uncrossed, that is, the image seen to the right is that of the right eye, to the left that of the left eye. Suppose, now, that the distance of the object from the plane of the fixation point is small, and the disparation, therefore, slight, there is no double vision, but the experience of relief or depth is given directly. According to one theory, that due to Hering, retinal disparation is an innate physiological factor on which our experience of depth or distance depends. Experiment seems to show that it is one factor. But it is by no means certain that this factor is innate.

Apart from retinal disparation altogether, it has been maintained that experience of distance and depth depends on sensations of the movements of the eyes in fixation of the object seen, converging or diverging movements, as the case may be. The fixating movements of the eyes are of considerable psychological interest. As we have already seen, the two eyes function together. As Titchener remarks: "We know that we have two eyes, but we know it only 'by accident.'"[1] The functioning together is due in part to the fact that they move together. They move up and down together, right and left together, and inwards together. The co-ordination is probably connate; at any rate it is present at a very early age. If one eye is closed, and the forefinger placed on that eye so as to feel the movement of the eyeball, it will be found that the closed eye moves with the other as the line of regard is changed from one point to another. The change of fixation from a near to a more distant point, or vice versa, is effected by movement of both eyes, and our sensations of movement might therefore serve as a basis for the perception of distance. It has already been shown that eye movements in the case of the adult are by no means prominent and definite factors in experience, and that our sensibility to eye movement is by no means acute. It is doubtful, therefore, whether we can account for the actual facts of our distance perception in this way. Moreover, it may be shown experimentally that distance perception is still possible when the possibility of eye movements has been eliminated by momentary exposure.

[1] *Text-book of Experimental Psychology*, vol. i., pt. i., p. 134.

There is still another factor which enters into our experience of depth, relief, or distance. When the object fixated is at such a distance that the distance between the eyes is not negligibly small in comparison, the views of the object obtained by the two eyes are not quite similar, or the images are not identical. This, then, may be an additional cue determining perception of depth. It is utilized in the case of stereoscopic pictures, which, when combined by means of the stereoscope, give the appearance of solidity.

As we have already indicated, a certain measure of depth perception is possible in monocular vision on the basis of the motor sensations involved in the alteration of the curvature of the lens. The eye may be likened to a camera. The retina represents the sensitive plate. But, whereas with the camera focussing is carried out by altering the distance between the lens and the plate, this distance is fixed for the eye, and focussing is done by altering the curvature, and, therefore, the focal length of the lens. This change in the curvature of the lens is effected by means of the contraction or relaxation of a muscle—the ciliary muscle. Up to a certain limit, therefore—the limit up to which there is a change in the curvature of the lens—we should expect on the basis of the sensations from this muscle to be able to perceive depth or distance in monocular vision. As a matter of fact we can, though very indefinitely. The motor sensations from the ciliary muscle are by no means distinct, unless for considerable differences of depth or distance. With experience and practice, no doubt, the judgment of distance in this way may be greatly improved, but normally the sensations involved in accommodation cannot be regarded as of any very great importance, at all events for the adult. It ought also to be kept in mind that changes in accommodation are always accompanied by co-ordinated changes in fixation of the two eyes, so that binocular vision might be said to be involved, even in this case.

A simple experiment to show the inadequacy of monocular accommodation for the perception of distance may be performed by letting the subject look with one eye through a wide blackened tube at a small bead suspended straight in front at a distance of about 14 inches, and then dropping balls, sometimes nearer than this, sometimes farther away, so as to fall across the field of vision. If the subject is asked to say whether these balls are nearer or farther away than that fixated, the

inaccuracy of his estimate of distance under these conditions will become at once apparent. For accurate scientific study of monocular perception of distance Hillebrand's apparatus is, perhaps, the best. In this two dead-black screens can be moved in front of a circular aperture, one from each side, so that each covers half of the field. At any particular moment only one is in place, and the subject regards the edge passing through the middle of the field. That screen is then moved out and the other moved in. Both screens slide along rods, and the distance from the subject can be read on a scale.

None of the factors we have considered can make any appreciable difference to our experience of objects which are at a distance beyond 20 or 30 yards. Yet we estimate distances beyond that. In such cases our perception of distance depends mainly on other psychological factors of the kind we might call "indirect." Differences in distinctness, size, light and shade, intervening objects, aerial perspective—these factors entering our perceptual experience as relational factors—determine our estimation of distance under these circumstances where none of the factors we have been describing can influence our sensory experience. It is an interesting fact that these indirect psychological factors, when represented by a painter in his picture, exercise a much greater influence when the picture is regarded with one eye than when it is regarded with both eyes. Both eyes seem, as it were, to insist that the picture is a flat surface.

The Localization of Sounds.—Some very interesting experimental work has been done on the localization of sounds. The special interest for the psychologist of such work lies in the fact that localization of sound is not localization in an auditory world, but localization in a visual or tactual world, whereas the localization of objects seen is in a visual world, and of touches in a tactual world. Auditory space is, in a sense, derivative or secondary. The reason for this, many psychologists would say, is that auditory sensations do not have the spatial attribute of extensity, so that the auditory world has itself no spatial content. On the other hand, it must be conceded that auditory sensations have the quasi-spatial attribute of voluminousness. But it is not, so to speak, within this voluminousness that sounds are localized; the sound with its voluminousness is localized in the world outside, the world of touch, movement, and sight. Hence the problem of the localization of sounds is a new kind of problem in the field of space perception, different from the

problem of the localization of an object seen or of a contact or pressure.

Sounds are localized with respect to direction and with respect to distance. The first is a function of binaural experience, the second not necessarily so. The fact that we have two ears placed at a certain distance apart involves the possibility of what we may call auditory parallax. That is to say, a sound will normally be heard differently in the two ears, unless its source is symmetrically placed in relation to them. Hence a sound which is not made in the median plane of the body—or in the *sagittal* plane, as this plane is usually designated when speaking of the localization of sounds—is generally located without much difficulty.

There is, as a rule, considerable confusion regarding the localization of sounds in the sagittal plane. With complex noises, however, the confusion is not nearly so great as we sometimes see stated. The best method for the study of the localization of sounds for direction is with the apparatus known as the *sound perimeter*. The essential part of this apparatus is a metal arm forming the arc of a circle, carrying at its end a telephone receiver. This arm can be moved in the horizontal plane, and in any plane perpendicular to it, so that the receiver is at a constant distance from the middle point of the line joining the subject's ears. Thus a click can be made in the telephone receiver—by breaking a primary circuit—at any point in the surface of a sphere, the centre of which is the middle point of the line joining the subject's ears. We can study localization in the sagittal plane very simply with the sound perimeter by selecting, say, seven different points in that plane, separated by 45° from one another, and giving the stimulus ten times at each, the whole in haphazard order, the subject being asked to locate the sound each time. It will be found that the localization is moderately accurate in a fair proportion of the cases. Most subjects, however, show a curious tendency, either to locate behind sounds actually in front, and especially below the horizontal in front, or to locate in front sounds actually behind. The first of these is, perhaps, the prevailing tendency, and it seems as if some subjects localize all sounds in the median plane, but not overhead, when the source of the sound cannot be seen, in some position behind (the eyes of the subject are, of course, closed). If a similar experiment be performed with sounds in the coronal plane—that is, the plane over the

head from right to left—it will be found that very few errors occur, and there is never any tendency to displace a sound from one side to the other.

These results at once point to some difference in the sound, as heard by the two ears, as the basis of our localization with respect to direction. All sounds except those in the sagittal plane will be nearer the one ear than the other, and hence, apparently, will give impressions of different intensities in the two ears. But mere difference of intensity will not explain all the facts. All sounds made in the sagittal plane give equal intensities in the two ears, so that it ought to be quite impossible to locate any sound in this plane, if difference of intensity in the two ears were the sole basis of localization. We have seen, however, that there is some ability to localize sounds even in the sagittal plane, and that sounds made above the head in this plane are usually correctly located. Hence, though intensity is certainly one factor, upon which the localization of sounds depends, it is equally certain that it is not the only factor.

If there are differences other than intensive in the impressions at the two ears, it comes to be an experimental problem to determine what these are. Another obvious difference in the impressions in the two ears of a sound outside the median plane will be a temporal difference; the sound will arrive at the nearer ear first. The fact that we are able from the start, without interruption, to localize continuous uniform sounds would seem to show that this is not an important factor. It has also been suggested that there is a difference of quality in the sounds at the two ears. Such a difference of quality could only arise in the case of a complex sound like a noise or a clang, and it can be shown that our localization of pure tones is much less accurate than in either of these cases. The difference of quality might be produced in various ways. On the one hand, if the sound was produced so definitely on one side of the head that a "sound shadow," due to the head itself, affected one ear, the sound might come to the two ears with a qualitative, as well as an intensive difference, since the sound shadow would tend to be deficient in the components of high pitch and short wave-length. On the other hand, the shape of the external ear would tend to exercise a modifying influence of a similar kind on complex sound-waves according to the direction from which they arrived. This latter fact would also explain how many

subjects can frequently distinguish between sounds behind and sounds in front, even in the sagittal plane.

Another very interesting difference, which might function as a factor influencing localization, is a phase difference at the two ears. If the two ears are not the same distance from the source of sound, the difference in distance may be such that the sound waves falling on the two ears are not in the same phase. For example, the rarefaction phase of the one wave might coincide with the condensation phase of the other. It has been shown experimentally that changes in the phase relations of tone stimuli reaching the two ears do produce changes in the apparent position of the source of sound. Thus the sound of a tuning fork can be led through a twice-bent tube to the two ears separately, and by means of a sliding piece in front slight alterations in the position of the fork, corresponding to phase differences at the two ears, may be made. Under these conditions it is found that the sound is localized within the head, but its position within the head changes with the phase differences at the two ears. The phenomena are complicated by the fact that there is bone conduction of sounds through the bones of the head from one ear to the other, and this consideration must also be taken into account in connection with the other phenomena we have just been discussing. Hence there is apparently more than a simple phase difference at the two ears to be taken account of; there is also a possible phase difference between two waves reaching the same ear, the one through the air, the other through the head. In this case there will be interference between the two series of waves—or, it may be, summation—involving an intensity difference in the sounds. It has been suggested, therefore, that phase difference affects localization indirectly by its influence on intensity.[1] Moreover, it has been argued that it is difficult to conceive how phase differences between the sound waves at the two ears can make any difference in the excitation of the receptor cells for audition, upon which our sensations depend. Recently, however, it has been shown [2] that, in spite of the difficulty in conceiving the *modus operandi*, phase differences do determine localization, independently of intensity differences.

All the factors, then, which can be shown experimentally

[1] See Myers, *Text-book of Experimental Psychology*, chap. xxi.
[2] Bannister, in *Brit. Journ. of Psych*., vol. xiii.

to influence our localization of sounds are: (1) differences of intensity at the two ears; (2) differences of a qualitative order due to (*a*) the sound shadow of the head, (*b*) the shape of the external ear; (3) differences of phase. The general findings from a qualitative study of the localization of sounds in the various planes are confirmed by quantitative study of the discrimination of differences of position. The threshold, for example, in front and behind, is much lower than opposite either ear.

Our estimation of the distance of sounds is independent of the fact that we possess two ears. It depends, in general, however, on the same factors as determine our estimation of the direction of sounds, with the exception of the last. On the one hand, the intensity of a sound diminishes as the distance of its source increases. Provided the sound is a familiar one, therefore, with a familiar intensity, its loudness at any moment forms the basis of our estimation of its distance. But there are also criteria of a qualitative order. Distance produces a different result on low tones and high tones, on noises and tones, on consonants and vowels, and these differences serve as a basis for our estimation in the case of unfamiliar sounds. On account of the different effect of distance on high tones and low tones, there is a change in the relative predominance of high and low overtones with changes in distance.

The Perception of Time

The problem of time perception must be distinguished from the wider problem of time estimation, which may be purely perceptual, but which may also involve factors belonging to higher mental levels than the perceptual. We are at present concerned only with perceptual time, with what has been called the "time sense." Two features of our sense experience offer themselves in explanation of our perceptual experience of time. On the one hand, there is the attribute of protensity or duration, belonging to all sensation. On the other hand, there is the experience of change or transition. The two factors operating together give us our immediate experience of a time continuum. Of course, explicit consciousness of duration as duration, or of transition as transition, belongs, not to perceptual, but to conceptual intelligence. Nevertheless, we have experience both of duration and of change, even when we have definite cognition of neither as separable aspects.

Fourth dimens.
I
II

Any sense stimulus involves a series of changes in our experience. Consider a visual stimulus. Apart from the period of latency, which is not experienced, a period of time elapses between the first consciousness and full consciousness. After the stimulus is withdrawn there is a period of fading away of consciousness, and there may be more than one succeeding phase of consciousness in the shape of after-sensations. Each phase also, so far as it is experienced, has an aspect of protensity or duration. Our perceptual experience of time, then, in its simplest terms, rests on these two features of our sense experience: on the one hand, the experience of changing phases, on the other hand, the attribute of protensity.

The Sensory Present.—The present moment is determined and defined for us by the sensory experience we are now having. This present, however, is not a point of time, but a duration. It represents a time interval. The *specious* or *sensory* present, as it has been called, is longer or shorter according to circumstances, and the various conditions upon which its length depends can be experimentally studied. It depends on the nature of the sense experience itself, on the relative ease or difficulty with which attention is maintained, on the condition of the organism brought about by fatigue, drugs, etc. So long as an interval of time falls within the sensory present, we have an immediate impression of it, and can estimate or reproduce it with a relatively high degree of accuracy. The sensory present may extend up to about four seconds with an effort of attention. Beyond a certain limit, however, an interval of time between two stimuli no longer gives a unitary impression; the interval breaks up into its component parts, and is only held together as a whole conceptually.

The immediate impression of a time interval between two stimuli is considerably modified by the nature of the stimuli, and the same interval may appear longer or shorter according as it is bounded by auditory or visual stimuli. With any particular type of sense stimulus there is always a definite interval which has a peculiarly "satisfying" character. For example, when two momentary sounds are separated by about half a second—more accurately ·55 second—the interval has this character. This "satisfyingness" is clearly related to the full development of the series of changes involved in a sensory stimulus, to which we have already alluded.

A time interval between two stimuli which is occupied by

other stimuli, that is, a "filled" interval, seems longer than an equal interval, which is not occupied by other stimuli, or is "empty." This is markedly the case where the stimuli are tactual. The phenomenon is analogous to the illusion of "filled and empty spaces," which we discussed in a preceding section. It appears to be due partly to the impeding of attention, and partly to the fact that the impressions filling the interval tend to interfere with each other's development. No interval, however, can be empty. There are always organic changes going on in the living body, and various organic rhythms, as, for example, in respiration or in the heart-beat, may constitute the basis of our estimation of the duration of a time interval. It is also characteristic of unpractised subjects, when estimating time intervals, to base their estimate on their own filling of the intervals with voluntary movements of various kinds. For example, they may "beat time" with hand, or foot, or head. As subjects become practised these aids to estimation tend to disappear, the more expert subjects feeling that they are a hindrance rather than a help.

The experimental study of the "time sense" may proceed by various methods, but the methods all belong to one or other of two types. They are either methods in which the subject is asked to reproduce a time interval, which is the type of method specially applicable to the study of rhythm; or they are methods in which the subject is required to compare intervals, which is the type of method upon which the most exact quantitative study depends. Under laboratory conditions the standard time interval in the first, and both intervals in the second, are usually given by means of a "time wheel." In this apparatus a pointer is rotated at a constant, known rate round a circle graduated in degrees. Contacts are placed at any points on the circumference, and a sounder or sound hammer in the circuit is thus caused to give a sound whenever the pointer passes one of these contacts. The sounds mark the limits of the interval or intervals with which we are working. It is obvious that if the pointer makes a complete revolution in 9 seconds, we can get an interval of 1 second by placing the contacts 40° apart, and so also of other intervals. If the subject is asked to reproduce an interval, we arrange so that both the standard interval and its reproduction are recorded on a smoked drum. Where the subject is asked to compare two intervals, we may either make the terminal sound of the one the initial sound of the other, or we may

interpose a pause of any desired length, within limits determined by the time of a complete revolution, between the intervals. This last arrangement enables us to study the effects of varying lengths of pauses. With relatively long pauses it may be convenient to use some method other than the " time wheel " for giving the intervals.

Our estimate of an interval within the sensory present is, apparently, subject to the general law that we overestimate short intervals and underestimate long intervals. The point at which we change from overestimation to underestimation may be called the " indifference point." At this point our estimation tends to be very accurate. The point has been found to vary slightly with different individuals, but it may generally be taken as lying between ·7 and ·8 second. Some investigators have found that odd multiples of this interval show also a high degree of accuracy of estimation.

Our sense of the lapse of longer intervals of time depends on complex and somewhat obscure conditions, but need not involve ideal representation, so long as the interval is not represented, or thought of, as a unity. In order to account for the facts we must assume, as Stout puts it, that "a succession of different experiences, or the duration of the same experience, produces a cumulative effect varying with lapse of time." [1] Within the sensory present this cumulative effect may easily be explained as a result of attention itself. But measurement of estimation of the lapse of time, approximately accurate, is by no means confined to periods within the sensory present, or even to periods of highly attentive consciousness. In such cases we must assume a cumulative effect of obscure organic changes, which never enter clear consciousness at all. There are other cases in which we must assume a cumulative effect, dependent perhaps partly on these same organic changes, and partly also on interest and attention, but the exact nature of this cumulative effect has never been clearly defined.

The part which affective factors play in our estimation of the lapse of time is well known. An hour may seem short or long according to the manner in which it has been spent, and the extent to which agreeable or disagreeable interest has been involved. Stout also calls attention to the interesting fact that a period of time, which seemed short in passing, may appear

[1] *Manual*, p 402, 2nd Edition.

long in the retrospect, owing to the many interesting events which occupied it. But this phenomenon is one involving ideal representation, and, therefore, outside the limits of our present discussion.

With respect to the comparison of two intervals separated by a pause it must be said that the conditions are somewhat complex. The results of investigation have been concisely summarized by Myers. In the first place "when the subject is allowed to make what pause he likes before he reproduces a given interval, the pause is relatively longest when the given interval is shortest," and "as the interval which he has to reproduce is increased, the pause absolutely increases up to a certain length of interval, after which it again declines." [1] In the second place, when a pause is interposed equal to the first interval, it seems longer than that interval, and tends, therefore, to affect the estimate of the second interval. In the third place, an unexpectedly long or short pause affects the attitude of the subject in such a way as to influence the estimation of the second interval. The phenomena involved in comparing two intervals, with or without an intervening pause, are strikingly similar to those occurring in the estimation of lifted weights. Side comparisons and the absolute impression play the same part in the estimation, and the interposition of a pause naturally increases the tendency to the occurrence of these phenomena.

Rhythm.—The apprehension or maintenance of a rhythm evidently depends on the perception of short time intervals, and the appreciation of regularity in such intervals. In the case of rhythm, however, the principles of the *Gestalt*-psychology once more apply. We have perception of a form or whole, which cannot be entirely explained on the basis of the sense data. Evidence is not far to seek. Apart from any objective accentuation, there is always a tendency for regularly repeated impressions, so long as the interval between them falls within the sensory present, to arrange themselves in regular rhythmical series. The beats of a metronome, for example, arrange themselves in twos or fours. When the rhythm is established, the first member of each group becomes accentuated, and seems to be louder than the others, while the immediately succeeding interval appears also longer. Precisely the same effect is produced by objective accentuation, but objective accentuation is

[1] *Textbook of Experimental Psychology*, chap. xxiii, p. 300.

not necessary. Moreover, the metronome beats can, at will, be grouped in twos, threes, or fours, the whole "forms" being modified as a result. Fives are much more difficult to maintain, and larger groups break themselves up, but this is a function of the span of apprehension.

The accuracy with which a rhythm can be maintained depends on the individual, on practice, and on the length of the interval between successive impressions. There is not a great deal of experimental evidence, and this whole field requires to be worked over, but the maintenance or reproduction of rhythm appears generally to be most accurate when the interval is ·7 second—the indifference point—and with more rapid rates the reproduction tends to be still more rapid, with slower rates still slower.

CHAPTER VII

ATTENTION

THE thoughts and ideas and sensations which we experience have been compared to a stream of consciousness. The stream flows incessantly and continuously, and only few of its contents can be separately experienced. The other elements are outwith clear consciousness, and, though experienced, are not separated out as single differentiated elements, but form part of the total sensory mass which assails us at every moment. Consider for a moment a simple example. We are sitting reading by the fire, attending to a story as it unfolds itself. We have become so engrossed in our book that we are totally unaware of the sensations of heat from the fire, of the crackling of the flames as they leap up and down, of the ticking of the clock, of the movements of our eyes, of the tactual sensations from our clothes, and of the kinæsthetic sensations from the various muscles of our body. And yet all these sensations are contributing to our total experience, and if one of them were absent or altered, our total experience would not be the same. These experiences which we do not clearly apprehend we may designate as existing in the *margin* of consciousness. The story on which our attention is riveted, and of which we are directly aware commands the *focus* of consciousness. Every state of attention may be considered in this way. Objects are continually passing from the margin to the focus, and from the focus to the margin. What was clear at one moment is dim the next, and what was but dimly noticed —if at all—becomes distinct. It may be asked, how do we know there are elements in the margin, if we are not aware of them? The obvious answer is, that if one of the elements ceased to yield its contribution, we should immediately observe a change. We are all aware of the sudden void which makes itself felt whenever the ticking of the clock ceases, although we had not attentively heard it before. We had grown accustomed

to it, and, to express the matter paradoxically, we only became aware of its existence when it ceased to exist. Similarly, the miller ceases to notice the continuous noise of the mill, and the factory worker hears not the constant whirr of machinery, which is deafening to the unaccustomed, while the roar of the train becomes non-existent for the traveller. Yet, if these respective noises abruptly stopped, a difference in the total experience of each would be inevitable. All marginal experiences may be considered as contributing a large share to our daily lives. They are ready at any moment to enter into consciousness—we can hear the ticks of the clock if we listen for them—but they do not enter consciousness until required. The mind, to a certain degree, but not exclusively, selects out those elements which are to form the focus. If considered from this viewpoint, we may define attention as the selective activity of consciousness.

The number of objects which can exist simultaneously in the focus of consciousness has been submitted to experimental investigation. The general opinion is that we can attend only to one object at one time. But this statement requires qualification; for an object may be of two kinds, either simple or complex. We regard a house as a unit, and as a single object; yet it consists of an infinite number of parts, windows, doors, chimneys, etc., each in themselves units. The "singleness" of the object, therefore, varies according to the purpose in hand. An object may be one single thing or it may be a number of things grouped together and regarded as a single object.

The method usually employed in this investigation is very similar in essence to a popular parlour game, and consists in the momentary exposure of a number of objects—dots, lines, letters, or colours. The time of exposure is very short, ranging from $\frac{1}{100}$ to $\frac{1}{5}$ of a second, so that eye-movements cannot take place, and in consequence the counting of the number of objects seen is avoided. The greatest number of items which can be recognized in such an instantaneous flash is 4 or 5. This is known as the span of attention, or the span of apprehension. It is interesting to find that instead of five separate letters, five short words can be recognized, and if the dots are arranged in groups, the same number of groups as individual dots can be discriminated. It is as easy to distinguish five pairs of lines as five separate lines. It will be evident that this power of apprehension will increase with age and practice; not that the

span of apprehension will increase, but that the units may become more and more complex.

The same principle holds when the objects are apprehended successively rather than simultaneously. If a number of sounds, for example, the beats of a metronome, are heard one after the other, but too quickly to be counted, then we can apprehend as many as 8 at a time. " If one group (the first member of which is accentuated by a bell) consists of eight taps, while another group (similarly accented) consists of seven taps, the subject can, without counting, distinguish the one group from the other; but beyond groups of eight taps, his judgments are unreliable." [1]

The explanation has been offered that what we do really perceive is a complex unit, and that the elements which constitute the complex are recognized later by a process of analysis. When the stimulus has ceased to affect the sense organs, a memory image or an after-image remains of the impression, and it has been suggested that the analysis of the complex into its units takes place after the withdrawal of the physical stimulus, and that each separate element is singled out by the attention being directed particularly to it. The counting of the dots or the lines, or the recognition of the letters, is carried out after they have ceased to be exposed. One investigator measured the duration of the memory image of a number of individuals, and his conclusions pointed to the fact that those whose memory image persisted for a long time after the original stimulus had been withdrawn, had a large span of apprehension. There seems, then, to be some truth in the assertion that the span of apprehension depends upon the memory image.

Fluctuation of Attentions.—Closely related to this problem is the question of the length of time we can attend continuously to a single object in consciousness. We talk of attending to a task for days on end, or for months, but that the attention is not steady or concentrated throughout is a matter of common knowledge. Even when we study a single proposition for a short time, we cannot say that our attention has been fixed upon it throughout, for now one aspect, now another has diverted our attention into different channels. That fluctuations occur is undoubted, but to measure these fluctuations in quantitative form is a matter of exceeding difficulty.

[1] Myers, *Experimental Psychology*, pt. i., p. 322.

It is possible, however, to measure these changes in the attention, if very weak stimuli are employed. The ticking of a watch provides an excellent illustration. The watch is held at such a distance from the observer that the ticking is barely audible—he can just hear it and no more, and although he listens attentively he will find that the sound is not constant, but comes and goes. This alternation of appearance and disappearance occurs at approximately regular intervals. If the subject lifts his pencil when he hears the sound, and lowers it when it becomes inaudible, the experimenter is able to record the number of fluctuations which have taken place within a given period of time, for example, one minute. It will be found generally that the attention fluctuates every 5 or 6 seconds, although records have been noted of a fluctuation only 3 seconds in duration—the shortest observed—the longest on record being 25 seconds. The period, of course, varies with the individual, and with the prevailing conditions of the experiment. A room where absolute quietness prevails is essential.

The same phenomenon can be observed with a very faint touch, and with a faint visual stimulus. For vision, a rotating disc gives the best results. A white disc with an interrupted black line drawn along one of its radii is most satisfactory.[1] When the disc is rotated, each separate portion of the black line mixes with the white of the disc so that the entire surface presents the appearance of a number of grey rings, each ring growing whiter and whiter (because of the greater admixture of white) as the edge of the disc is approached. The observer, with head steady in head-rest, fixates the faintest grey band he can distinguish, and, as in the case of the auditory stimulus, notes the fluctuations which occur. After a little practice, the subject is able to record these fluctuations by pressing a rubber bulb when the grey disappears, and relaxing the pressure at its reappearance. The bulb is connected with a tambour whose lever traces out the fluctuations on a kymograph, or smoked drum.[2] A second lever immediately below the lever of the tambour records the time. After one revolution of the drum, the subject should be rested, as fatigue sets in very quickly. An introspective account from the subject will prove of con-

[1] This is known as the *Masson* disc. This disc should have a diameter of 20 cms. The black line should be 5 mms. broad, the interrupted black pieces 5 mms. in length, the white spaces between 5 mms. in length. (See Fig. 11).

[2] Or a Reaction Key may be used.

siderable value. Ten such trials at least are necessary before any valid result can be obtained. The subject's introspection can be written between the trials.

These fluctuations of attention have received different explanations from various investigators. It is convenient to classify these theories in two groups: *peripheral* theories, which postulate some condition of the sense organ as the explanatory factor, and *central* theories, which attribute the cause to the

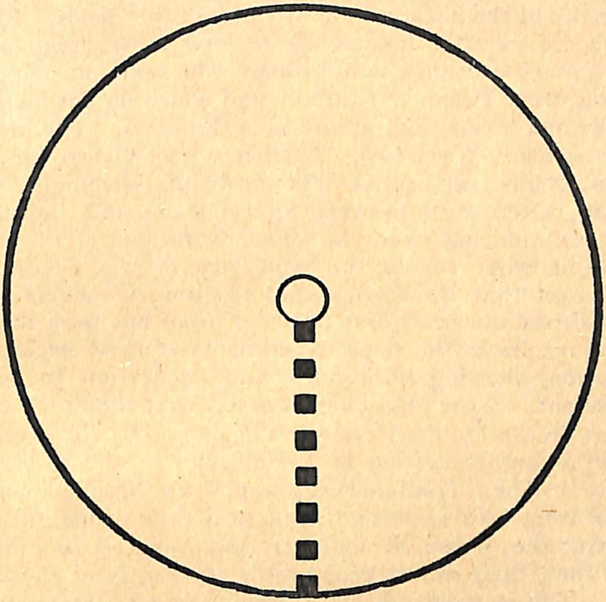


FIG. 11.—Masson Disc.

nervous centres. It has been suggested that in vision, for example, the fluctuations are caused by some muscle which periodically decreases the clearness of the object in the fovea. This has been attributed to the ciliary muscles as fatigue sets in; on this fatigue with subsequent recovery are said to depend the fluctuations of attention. That is, the accommodation muscles have been suggested as the predisposing cause. But these muscles have been found to be unnecessary in the effecting of such a condition, for fluctuations have continued after the

muscles have been paralysed by homatropine. Nor can involuntary eye movements, causing new parts of the retina to be constantly stimulated, serve as an adequate explanation. This explanation fails to account for the uniform regularity of the fluctuations. Similarly, in the case of auditory fluctuations, the phenomenon still continued in the case of one individual who had no tympanic membrane. The peripheral theories, therefore, seem to be of little validity.

The central theories justify their claims by accounting for the occurrence of the phenomenon in various other fields. Fluctuations occur in after images, as we saw in studying positive and negative after-images in vision. The same phenomenon is observed when two colours are viewed which do not blend, and now the one predominates, and now the other. The attention fluctuates between the two. Further, a geometrical figure with an ambiguous perspective fluctuates at seemingly regular intervals, alternating between the concave and the convex. The fluctuation has been explained by fatigue of the cortical cells. But what causes the regularity of the fluctuations? Some assert that the cardiac and respiratory movements are the predisposing causes, but no valid proof has been obtained, and the results of the same experiments seem to negative the assumption, showing both pulse and respiration to be alike independent. Some physiologists assert that they may be connected with the Traube-Hering waves, caused by the rhythmical contraction and relaxation of the muscles in the walls of the arteries. "These Traube-Hering waves run through a complete cycle in from 6 to 15 seconds, but in a time of mental strain, as during the period of concentration required to mark the fluctuations, their rate is kept pretty constantly at the shorter period. This corresponds very closely to the time given by most investigators as the average length of the attention wave."[1] The period of the waves can be measured by the plethysmograph which registers the increase or decrease of the volume of the arm.

Division of Attention.—It is no uncommon thing for individuals to report that they can attend to two tasks simultaneously. Their attention appears to be comprehensive enough to embrace the successful carrying out of two disparate activities. The study of the problem by means of a simple

[1] Pillsbury, *Attention*, p. 75.

experiment throws much light upon it, and offers the probable explanation. Write down as quickly as possible the letters of the alphabet, repeating the series until one minute has elapsed. Count the number of letters written down. Now add aloud 3 to each number, beginning with 1, e.g. 1, 4, 7, 10, etc., for one minute, and record the highest score obtained. Finally, perform these two tasks simultaneously for one minute and notice the results. There will be apparent a failure to divide the attention equally between the two tasks, and, in consequence, the two tasks are badly carried out. There is a tendency, during such an experiment, for the attention to oscillate between the two activities; it is rare, indeed, for them to be carried on conjointly. If this latter does occur, it means that the one process has become automatic for the time being, and can be carried on mechanically without the active interruption of consciousness. This explanation accounts for many of the so-called cases of attention to two different activities, such as knitting and reading at the one time: the former has become so automatic that all the attention can be directed to the latter, and attention is only required for the former at intervals when some special problem presents itself, such as a dropped stitch. Divided attention, therefore, is, strictly speaking, an impossibility, and the power, reported of some historic personages, of being able to dictate four letters while writing a fifth is due to rapid oscillation of the attention.

Distraction.—The effect of distraction upon attention is of considerable interest. The lay mind immediately classifies distraction as one of the conditions causing bad workmanship and inducing lack of concentration of attention. As Hollingworth expresses it, "Evidence could be adduced of the disturbing effects upon efficient work of an aching corn, an itching nose, an ill-fitting collar, a broken finger-nail, the hum of conversation, or the rattle of a typewriter." [1]

But experimental evidence yields conflicting results. In some cases the distraction is deleterious, in others, however, the paradoxical result is obtained that better work is performed during distracting influences. If we ask an individual to cross out all the *a's* and *e's* in a page of print as quickly as he can for a quarter of an hour, and then to repeat the experiment under distracting conditions, subjecting his left hand to electric shocks, or causing distracting sounds in his neighbour-

[1] *Applied Psychology*, p. 131.

hood, we shall find in all probability that the distraction seems to have increased his output. From this viewpoint, the distraction may be considered as an incentive leading to increased attention to the task; the individual, as it were, "rises to the occasion" and draws upon his reserve energy, or, to express it in a different way, his pugnacious instinct is challenged and must respond. This result of increased output seems analogous to the law of *dynamo-genesis*. The same phenomenon seems to be at work as when a beam of light falls on the eye when the knee is struck a light blow. The combined stimuli cause the knee jerk or reflex to increase in violence. Similarly, the distracting influence may issue in better work.

The effect of distraction on different individuals is a very varied one. In some cases it is impossible for certain people to overcome disturbances in their environment, the least noise or sound of voices being sufficient to draw away their attention from the task in hand. For others, the converse appears to hold true. Absolute quietness, for this second class, lacks the necessary incentive for work. The writer is acquainted with one student who finds home too quiet for study and who prefers, instead, the subdued hum of a reading-room.

If the distraction is slight and continuous, accommodation will soon set in with possibly no detrimental result to the organism. If, on the other hand, the distraction is violent in character and occurs irregularly, it may result in increased attention, but what does that attention involve? It involves additional expenditure of energy on the part of the organism to overcome the distraction, thereby inducing an acceleration of the onset of fatigue, cumulatively at least. This entire problem requires further experimentation before definite conclusions can be drawn, and before a decision can be made as to the precise meaning of the various phenomena.

Expectant Attention.—We shall find when we come to discuss reaction time[1] that the direction of the attention causes a difference in the length of the time of the reaction, and we shall observe that when the attention is concentrated on the response, the time of reaction is considerably shorter than when the attention is directed on the stimulus. This is an instance of expectant attention. The mind is prepared beforehand to receive the expected stimulus, and in consequence the reaction takes place almost instantaneously.

[1] Cf. p. 158.

This phenomenon is a familiar one of everyday life. What we are expecting tends to take place. "When watching for the clock to strike, our mind is so filled with its image that at every moment we hear the longed-for or dreaded sound. So of an awaited footstep. Every stir in the wood is for the hunter his game; for the fugitive his pursuers." [1] The interpretation varies according to the idea in the mind which is already half-prepared for the presentation, and only requires the presence of a stimulus to develop it into an actual sensation. In seeking for a book in a book-shelf, one unacquainted with the book takes considerably longer than one familiar with it, the reason being obviously that the latter has a definite image of the required article in his mind, which considerably facilitates his search. The same phenomenon is seen in the case of puzzle pictures. The one phase of such a picture so holds the mind that it inhibits the entry into consciousness of the hidden picture, and this latter becomes difficult to decipher. But once the puzzle has been solved, it is remarkable how easy it is to locate what was once so difficult, and one wonders how it is that it was unnoticed for so long. The simplicity is now explained by the fact that we know definitely what to look for.

One other point demands consideration in regard to expectant attention. If two stimuli are presented simultaneously to two different sense organs, they are not experienced at the same time. If the stimuli are light and sound respectively, the sound is always heard before the visual sensation is experienced. This is partly due to the longer latent time of all visual sensations. But the time order is also affected by the direction of the attention. That sensation which the subject is expecting tends to be experienced the first.

This result can be obtained by using what is known as a "complication clock." This consists of a large clock-face over which moves a large index hand. At one point in its course a bell rings. The subject is asked to observe the position of the hand at the stroke of the bell. If the subject concentrates on the moving hand (the visual stimulus) the bell is heard too late, the result is a positive time displacement. If, on the other hand, the ringing of the bell forms the focus of attention, it is heard too soon, and a negative time displacement occurs. The displacement varies according to the practice of the subject.

[1] James, *Text-book of Psychology*, p. 235.

and the speed of rotation and size of the index hand. Rapid speeds tend to facilitate great positive time displacements, slow are more liable to give rise to negative time displacements, and between these two an indifference point can be obtained at which no displacement occurs.

Conditions of Attention.—The conditions of attention may be conveniently divided into two main groups, which may be designated as subjective and objective respectively; in the former case, attention is determined by our interests and dispositions and prevailing tendencies; in the latter case it is wholly determined by some external factor in the stimulus itself. Treated from the biological point of view, attention is regarded as the adjustment of an organism to its environment. "What actually happens is, that an organism adjusts its bodily and mental attitudes so as to be in the most adequate relation with significant stimuli in its environment; and when this occurs on the conscious level of behaviour, we say that the organism "attends to" these stimuli; that the object is "interesting" to the creature . . . and what essentially is an "interest" but the readiness to function of an inner disposition, a tendency, a wish?"[1] Our prevailing dispositions, our moods, our instincts, are all effective in determining the direction of our attention.

The objective conditions depend on external factors, and attract the organism through the sense organs. Any object by reason of its intensity alone may force itself into consciousness, as, for example, a very loud sound, a bright light, or an obnoxious odour. The brute force of the stimulus is sufficient to attract the attention, even, it may be, against the volition of the individual. With a weak stimulus, a change in intensity may serve the same purpose. "The noise of the train upon which we are riding passes unnoticed after a short interval, while the whirl of the train which passes on the parallel line, although it does not add very greatly to the din, will be noticed at once."[2] A negative change may cause the same effect. A sound passes unheard until it suddenly stops, and its cessation attracts attention, as, for example, the ticking of a clock. Further, a weak stimulus may pass unheard, but by summation effect alone it becomes efficacious and thrusts its way into consciousness. A faint tap fails to attract notice, but if repeated a number of times, it by its persistency alone attracts the

[1] S. S. Brierley, *An Introduction to Psychology*, p. 55.
[2] Pillsbury, *Attention*, p. 28.

attention. This is strikingly seen when a person is absorbed in reading, and only responds to the calling of his name after it has been repeated two or three times.

Anything unexpected or novel attracts the attention, and the advertiser who inserts his notice upside down is aware of this law. A movement in the field of vision is sufficient to draw attention to an object which otherwise would have escaped observation. Further, an object by its bigness or extensiveness is more likely to attract attention than one of smaller bulk.

Apperception.—Apperception is influenced by the dominant interest of the individual. We have all had the experience of reading a word in a page of print and then fruitlessly endeavouring to locate it. In proof-reading the author is a bad corrector of his own efforts, for he does not read the words as they are, but reads them as they should appear; for this reason he passes over many printer's errors, and in consequence one unacquainted with the text is more reliable for the simple reason that he reads the actual words as they are printed.

To a geologist the stones by the wayside have an appeal which does not exist for the mind of the uninitiated. The former can fit them into his pre-existing system of knowledge. A sunset to one may cause no alteration of the emotions; from another it will bring forth exclamations of delight.

Seashore [1] suggests a rather interesting and simple experiment which brings out this point with excellent clearness. Make a large blot of ink on a sheet of clean white paper; cover it with a second sheet to make the blot irregular. Make other two such blots in the same way. Then ask a number of subjects to write down what the three blots represent. It is interesting to note that the interpretations vary according to the interests, habits, and recent experiences of the individual, and rarely are two alike. But each observer is able to understand the other's interpretation once it has been indicated.

An apparatus used in connection with the span of apprehension also provides interesting material for investigations into apperception. A sliding shutter with an aperture sufficient to expose a white card is set up before the subject. He fixates the place where the aperture is, and once the spring of the shutter is released, the card is exposed momentarily to view. Instead of exposing a number of dots, letters, etc., as we should do if

[1] *Elementary Experiments in Psychology*, pp 144-5. See also chap. xiv.

testing for the span of apprehension, one long word is exposed, familiar in form with some well-known word, yet not quite identical as regards individual letters, for example, *extravaganza.* The subject catches a glimpse of the word as it is revealed in momentary exposure, and hazards a guess at it. It will be found that on the basis of the results obtained the subjects can be divided into two types—what may be called, on the one hand, the *fixed* type, and on the other hand, the *fluctuating* type. The fixed type gives a whole word to begin with (e.g. extravagance) and then corrects it gradually; the fluctuating type gives the beginning or the end of the word only, and builds it up by degrees. The fact that a word is not read by analysing it into its components, but that we recognize it from the general impression it makes on our sense-organs, goes far to explain many of the errors made by children in reading. That a child will mistake one word for another is a source of irritating wonder to the teacher, but such reading or apperception experiments provide the clue. Further, it is only by such methods that any speed in reading can be obtained, for if we were to analyse each word, our reading would be a laborious process.

Motor Accompaniments of Attention.—That each state of attention is accompanied by certain motor phenomena is well recognized. In hearing, for example, the sense organ is attuned to the reception of the stimulus, the whole body is tense, and changes in the circulation and respiration take place. To investigate changes in respiration a pneumograph (see Chapter XI) is so fixed that the lever of the tambour connected with it records on a travelling smoked drum. The time is marked by means of a second lever immediately below it. Allow the normal breathing of the subject to be recorded for two minutes, then with eyes closed give the subject an arithmetical problem to work out mentally, such as four digits multiplied by four digits. The difference in breathing is very perceptible during this concentrated attention, and it is interesting to watch its return to normal again. Concentrated attention makes the respiration shallower and more rapid. Sometimes the breath is held altogether, and a yawn or a sigh is an indication of relaxation from a state of prolonged attention, and compensation for deficiency in oxygen due to the shallower breathing. The other motor phenomena may be investigated by analogous methods which will be described in subsequent chapters.

CHAPTER VIII

THE STUDY OF ACTION

THE experimental study of action forms a very important part of experimental psychology, and many interesting and valuable results have attended investigation in this field. The stimulus to this kind of work seems to have been originally given by the science of astronomy, the earliest "reaction-time" experiments, as the psychologist calls them, having been carried out by astronomers. Astronomers, working together and apparently under the same conditions, frequently found in registering the time of an astronomical event like the transit of a star that there was a quite significant discrepancy between the times registered by the respective observers. Enquiry into the cause of such discrepancy led them ultimately to the performing of experiments of precisely the type which the psychologist now makes in the psychological laboratory. This kind of work was next taken up by the physiologists in connection with their study of the rate of transmission of nervous impulses, and from them it was handed on to the psychologist.

Let us consider, in the first instance, what takes place when we respond with a movement to a given signal. To understand clearly the processes involved, we must consider briefly the structure of the nervous system.[1] When an individual responds to a signal with a movement, say of the hand, a complete chain of events must take place. This chain can be divided into three distinct sections. The signal—a sound, or touch, or light—affects a sense organ, causing an excitation there, whereupon a "message" is conveyed along certain nerve paths to the brain (or, it may be, only the spinal cord) in the form of a nerve impulse. This impulse is then redirected to the muscles by means of which the movement of the hand is effected. Hence

[1] See Appendix A for a fuller discussion.

the three essential parts of our chain are: (*a*) the events in the receptor or sense organ (the ear, the eye, etc.); (*b*) the events in the conducting nervous paths (composed usually of two or more neurones); and (*c*) the events in the effector organs (muscles or glands). In general there are two conducting paths. Those neurones or nerves, to use the more popular form of speech, conducting the impulse from the sense organ to the brain or nervous centre, are known as *afferent* nerves; those which conduct the impulse from the nervous centre to the muscle or gland are known as *efferent* nerves. The exact relations between the two become clear when we study the structure of the nervous system as a whole.

The nervous system may be considered as built up of a very great number of nerve cells or *neurones*. The neurone consists of a cell-body with its processes—the *axone* and *dendrites*. The axone is the process by which impulses are conducted away from the cell-body, while the dendrites convey impulses towards the cell-body. While the structural unit of the nervous system is the single neurone, its functional unit is the sensori-motor arc or the reflex arc, which consists of at least two neurones, a *sensory* neurone to take the nervous impulse from the receptor, and a *motor* neurone to carry it to the effector. When an impulse traverses a reflex arc a simple reflex movement takes place, as an illustration of which we may take the contraction or dilation of the pupil of the eye as a result of the intensity of the light falling upon the retina. In such simple reflexes conciousness probably plays no part, so far, at least, as higher organisms are concerned. If we decapitate a frog, leaving the spinal cord intact, various reflex actions can still be evoked. Stimulation of the hind foot will cause a defensive movement of the other foot to remove the irritant. So, also, in the case of the jelly-fish, which has the simplest kind of nervous system, connecting a few sense-organs with a few muscle fibres, the stimulation of a sense-organ involves contraction of the muscle fibres associated with it, and the issue is a simple reflex action. This simple reaction of an effector to the stimulation of a receptor is thus characteristic of all nervous systems, and such a simple response forms the basis of many apparently complicated actions. In the case of higher organisms at least, a simple reflex action rarely takes place in isolation, since the parts of the nervous system are all so closely connected together that the stimulation of one receptor may involve the activity of a con-

siderable number of motor neurones. That is, a single sensori-motor arc rarely, if ever, functions alone. Practically the whole nervous system may be affected by the stimulation of one receptor.

Consider for a moment the nervous system from a biological point of view.[1] Low down the scale, but above the jelly-fish, we find an organism composed of a number of segments. This is the worm type. In this type each segment may be regarded as independent at the start, and as self-contained, comprising within itself its own sensory and motor nerve fibres, so connected that the exciting of an impulse in a sensory nerve causes a reaction in one or other of the muscles. The sensory and motor nerves are linked in various ways to form many sensori-motor arcs, and the cell-bodies are grouped together to form a cluster or *ganglion.* Each segment can apparently act independently, but if any movement of the whole body is to be achieved, co-operation must take place between all the segments. In other words the separate nervous systems must be united in some way. This union is effected by a long line of nerve substance, running through practically the entire length of the organism. This is the origin of a spinal cord. There is an analogous arrangement for the provision of a common food store (the alimentary canal). As an organism of this type rises in the scale of life, the front segment will show a development in sensitivity, simply because it is the front segment, and sense organs of various kinds will make their appearance in association with it. Consequently, there will be a considerable augmentation of the number and interconnections of the sensori-motor arcs in that segment. Further, since the remaining segments must function in co-operation with the leading segment, the communication between it and them must be improved and increased. The ganglia associated with the sense organs become highly developed, and a brain is thus constituted, which, as it were, takes over the command of all the minor nervous systems in the other segments.

The integrative action of the nervous system now becomes evident. Whenever a nervous impulse traverses a sensory nerve innumerable motor nerves may be affected. The movement of the whole organism may take place, a movement which is perfectly co-ordinated, the function of which is to benefit the

[1] See McDougall's *Physiological Psychology*.

organism as a whole. We can distinguish different levels at which this co-ordination takes place. At the first or spinal level, the stimulation of a receptor evokes an immediate response from a corresponding effector or group of effectors, the nervous impulse passing by way of sensori-motor arcs which are relatively simple and direct. "Thus, if the sole of the foot is pricked, most men and most animals will quickly draw away the foot. . . . They (the physiologists) have shown that the prick excites a nerve in the foot, that this excitement spreads up the foot to the spinal cord as a wave of physical change (not unlike a current of electrical change in a telephone wire), leaps across from the sensory nerve to a motor nerve (much as the electric spark leaps from one terminal to another), and so issues along the motor nerve, and, reaching the muscles of the leg, causes in them an explosion, which in turn causes them to contract and so withdraw the foot." [1]

The second level is formed by the growth of branches from the sensory nerves of the arcs of the spinal level. These connect up with other sensory nerves, additional connecting neurones come into existence, and the new arcs are completed by returning to motor neurones, those corresponding to the original sensory neurones and others. Arcs of the second level are thus formed. The new cell-bodies cluster together, and with the cell-bodies of the neurones from the sense-organs in the head form one large ganglion, which is the rudimentary beginning of a brain. Acts involving complicated co-ordinations like balancing and walking are carried out by the arcs of the second level.

The third level represents still more complex nervous connections. More intricate connecting paths are formed between the arcs of the second level, which in their turn, as we have seen, represent combinations and co-ordinations of arcs of the first level. As a result the brain increases in size. In man and in some of the higher animals the arcs of the third level are represented by the so-called association areas of the cerebral cortex. These arcs underlie the highest processes of mental life, and the greater development of these areas is associated with those mental capacities, which give man his marked superiority over the lower animals. Upon these areas also progress depends, for new arcs and combinations of arcs can be formed as a result of learning processes.

[1] McDougall, *Outline of Psychology*, p. 22.

The arcs of the first level are naturally the most fundamental and stable. As the arcs of the third level are the last to develop and the most complex, so are they the most unstable. Under the influence of a drug, or with the beginning of decay owing to age or disease, the highest nervous centres are the first to be affected. The reflex arcs of the first and second levels are, in the main, congenital, while the arcs of the third level have to be built up in the course of the life-history of the individual. Thus when a child is born, the arcs of the first level, controlling heart-beat, respiration, etc., are in complete working order. The second level arcs develop normally within a short period. But the third level arcs develop with the progress of the child's life and experience, and keep on developing till late in life.

Let us now turn again to reflex action, and consider it more carefully and in somewhat more detail. A reflex action is usually defined as an inherited muscular or glandular reaction, which is determined immediately by the stimulation of a receptor and the consequent excitation of an afferent sensory neurone, and which follows immediately upon such stimulation and excitation. The contraction of the pupil in bright light, the knee jerk, and the pouring out of saliva into the mouth when food is taken may be cited as illustrations.

For practical purposes reflexes may be roughly divided into two classes, purely physiological reflexes, and conscious reflexes. The former fall entirely outside consciousness. The contraction of the pupil when a bright light falls upon the eye is an example. Consciousness does not play any part in determining this reaction, nor are we conscious of the reaction itself, either in process, or after the event. In the conscious reflex, on the other hand, though consciousness has no share in bringing about the response, there is awareness in varying degrees of the reaction in process. The fact of an accompanying awareness involves a certain measure of control, the extent of the control varying with the degree of the awareness. Thus, coughing is a reflex caused by irritation of the mucous membrane of the throat, and, since it is a conscious reflex, it can be controlled to a certain extent. The cough may be inhibited, either temporarily or permanently, and the reaction may also be produced voluntarily.

Another more important classification of reflexes is into unconditioned or primary and conditioned. Every reflex has its own appropriate or adequate stimulus. When evoked by

this stimulus the reflex is unconditioned or primary. But it is possible to elicit a reflex, under certain conditions, by a stimulus other than the adequate stimulus. Such a reflex is known as a conditioned reflex. Whether all reflexes can become conditioned can hardly be said to be proved, but such evidence as we have points that way.

The study of the conditioning of reflexes may be said to have begun with the work of Pavlov and Bechterew. Most of the facts were known previously, but these workers developed technical methods by means of which a much more detailed and elaborate study of the phenomena was rendered possible. Pavlov's work is the better known. He devoted particular attention to glandular responses, and his classical experiment was the study of the salivary reflex as conditioned by stimuli other than the presence of food. He found that when a bell was rung constantly at the same time as a dog was given food, the sound of the bell in time produced a flow of saliva even in the absence of the food. The salivary reflex had become conditioned. By an ingenious arrangement he was able to record and measure the flow of saliva under different conditions.

Conditioned Reflex Methods in Psychological Experiment.—A recent development in experimental psychology of great interest has been the employment of conditioned reflex methods. Both glandular and motor reflexes have been used. The use of the salivary reflex in the human being, as Pavlov had used it in his experiments with the dog, was made possible by a simple apparatus devised by Lashley. This apparatus consists of a small metal cup, which can be placed over Stenson's duct in the inner wall of the cheek. A tube of small bore carries the secretion from the duct out at the corner of the mouth, so that it can be collected and measured. By means of this apparatus it is possible to measure the stimulating effect on salivary secretion of the smell, the sight, or the touching of food. The psychogalvanic response, which depends on the activity of the sweat glands,[1] and which will be described later, may also be used in certain psychological investigations depending on the conditioning of reflexes.

A simple arrangement described by Watson[2] enables us to study and employ conditioned motor reflexes. The palm of the hand is placed on a metal plate and the point of the middle

[1] Recent work seems to point to another conclusion. See *Nature*, October, 1926.

[2] *Psychology from the Standpoint of a Behaviourist*, p. 32.

finger brought into contact with a metal bar. The plate and the bar are connected respectively to the two terminals of the secondary coil of an inductorium. Thus a shock can be given to the hand, the effect of which is the reflex withdrawal of the hand. On the middle finger is placed a light cork saddle attached to the rubber membrane of a tambour. We can thus record on a revolving smoked drum the movement of withdrawal of the hand. It is a simple matter to record on the same drum the time of application of the stimuli, both the electric shock which is the normal or adequate stimulus for the reflex, and also the stimulus to which we desire to attach it, say the ringing of an electric bell.

The conditioned reflex thus becomes a new instrument in the hands of the psychologist. How potent the instrument is, it is as yet impossible to say. But it is certain that the conditioned reflex can be used in cases where it is impossible to use a verbal response to determine such matters as sensitivity, discrimination, and the like, as for example in the case of deaf and dumb subjects, or infants, or pathological cases of various types. It has already been used for such purposes in animal psychology with fruitful results. Hence its employment with the human subject will be watched with great interest.

Reaction Time.—From the study of reflex action we pass naturally to the consideration of reaction time investigations. We have already shown how the psychologist came to be interested in the time taken to respond to a signal or the reaction time. This can be measured approximately in a very simple way. We arrange, say, ten persons in a circle, so that the right hand of each individual is resting on the left shoulder of the individual next to him. One person in the circle holds in his left hand a watch which records tenths of seconds. He taps the shoulder of the individual next to him and simultaneously starts the watch. All are instructed to pass on the tap as soon as they receive it. Consequently, the tap travels round the circle, and when it reaches the originator he stops the watch. The time recorded is the total time taken by all the individuals in the circle to respond to a touch stimulus. Divided by ten it will give us the average reaction time to touch of one individual to a fair approximation.

For the detailed study of reaction time we must deal with individual subjects. The course of procedure followed is always more or less the same. A prearranged signal—a sound,

or a light, or a touch—is given to the subject, and he is instructed to respond as quickly as possible by raising his finger from a reaction key which he is pressing. The time between signal and response may be registered graphically on a smoked drum. There are various devices for securing this, but the simplest method is to arrange for the closing of a circuit by the signal and the breaking of this circuit by the reaction, a marker-magnet in contact with the smoked surface being placed in the circuit. If, at the same time, we record on the smoked drum the vibrations of a tuning fork, either directly or by means of another marker-magnet, we have everything necessary for the measurement of the time. The fineness of our measurement will naturally depend on the vibration rate of our tuning fork, but for most purposes a measurement in hundredths of a second is sufficiently satisfactory. For finer measurements than this some kind of chronoscope is generally employed.

From investigation on the point, it has been observed that the length of reaction time varies according to the direction of the attention. If the individual concentrates on the stimulus he is going to perceive and thinks little of the muscular response he is going to make, the time will be longer. On the other hand, if an individual places his full attention on the muscular response, his reaction time will be shorter. In the first case we have what is termed a *sensorial* reaction, in the second, a *muscular* reaction. The following table[1] shows this difference :—

Stimulus.	Muscular Reaction.	Sensorial Reaction.
Sound	125 σ	220 σ
Light	175 σ	270 σ
Touch	110 σ	210 σ
Heat	130 σ	190 σ
Cold	115 σ	150 σ

These figures express in thousandths of a second (or σ) the difference in length of reaction time, according as the attention is directed on the stimulus or on the response. Further, they clearly show that the reaction time varies according to the nature of the sense organ involved. It will be observed that

[1] This table is quoted from Myer's *Experimental Psychology*, vol. i., p. 126.

cold and touch yield the quickest responses, and that light requires a long reaction time, probably owing to the development of photo-chemical changes in the retina. Taste and smell give the largest reaction times of all. In the case of sound, it is interesting to note that noises give a shorter reaction time than tones. In all cases the muscular reaction is clearly indicated to be much speedier than the sensorial. If we were to test these two types of reaction over a period, one further outstanding difference would be revealed. On looking over our column of results for sensorial reaction we would see that they clustered fairly closely together; but, on glancing over our second column of muscular responses, a much greater variability would immediately become apparent, the individual measurements diverging greatly from their average.

The fact that a muscular reaction time is shorter than a sensorial is not surprising. For if we have the finger ready to respond whenever the stimulus is present, it means that the reflex arc is prepared for action. The muscles are in a state of tension, and the motor neurone is ready to discharge whenever it receives the message. This hair-trigger attitude is quite different from the attitude in the sensory reaction. In this latter, the reflex arc cannot be established until the stimulus is perceived, and the motor neurones are therefore not in the state of expectant readiness which is so characteristic of the muscular reaction. As might be expected, the subject whose attention is fixed on his reaction may respond "wrongly," that is, any extraneous or accidental noise (especially if the stimulus is a sound) may tend to evoke a reaction. James states the case aptly in his words, "The signal is but the spark which touches off a train already laid." Or a subject may respond "prematurely," that is, he reacts before the stimulus can have been perceived by him; or he may give a "delayed" reaction, in other words, react after having actually given, or almost given, a "wrong" reaction. These mistakes rarely occur in sensorial reactions. The reason is that the muscular reaction is closely allied to a pure reflex action, involving an arc of the first or spinal level. If such is the case, we are merely measuring the speed of the nervous discharge.

A third type of reaction is known as the natural reaction. In this type, the subject's attention is left undirected. His instructions are merely to respond whenever he is aware of the stimulus. The time for natural reactions lies intermediate

between those for sensorial and muscular reactions. But, although the attention may be undirected, some individuals naturally give sensorial reactions ; others give naturally muscular reactions. In this respect great individual differences are revealed. If the type of reaction is fixed, it is not easy to change over from the one to the other. Particularly is this true in the case of muscular reagents. For them it is sometimes almost impossible to fix the attention on the stimulus, and place the minimum of attention on the response.

Reaction time varies to a considerable extent with age. Old people and children give long reaction times. This seems to be accounted for by lack of the power of concentration, and the absence of the favourable attitude. Further, reaction time can be greatly reduced with practice. This applies more to the sensorial reaction than to the muscular reaction, and is due in the main to a better adaptation to the experiment. The time taken to react sensorially, nevertheless, can be so reduced that it closely approaches the muscular reaction. In the case of athletes, it may be beneficial to practise muscular reactions. In America, where the reaction times of athletes have been investigated, long distance runners are found to have much slower reaction times than sprint runners.

Fatigue lengthens the reaction time, and drugs have the same effect. If the stimulus is very faint, the reaction time is considerably lengthened. When the stimulus in its presentation varies in intensity, or when the stimulus is presented without any warning to the subject, the reaction time may show an enormous increase. The shortest reaction time is obtained when a warning signal precedes the stimulus at a regular interval of about two seconds.

A simple reaction, although taking so short a time, involves a train of processes on the mental side as well as on the physical. We have already seen on the physical side the complexities of the series. The stimulus strikes the sense organ, the message is carried along the afferent nerve to the spinal chord, and hence to the brain, from there back again to the spinal cord, and along the efferent nerve to the muscle which controls the response of the finger. The reaction time includes all these physical happenings. The real mental process is associated with processes, within the brain, and somehow the mental act of perceiving the stimulus and the volition to move the hand take place there. An endeavour has been made to eliminate

the time of the physical chain of events by calculating the rate of transmission of nervous impulses, and by elimination to arrive at the "reduced" reaction time, or the total time employed in the purely mental aspect of the process. Our knowledge, however, of the physiological changes, is too inaccurate.

Now what is it that occurs in the "reduced" reaction? Can we analyse the mental processes at work? The mental processes are threefold, the perception of the stimulus, its apperception or recognition in consciousness, and the act of volition which is essential before the response is effected. The distinction between the first two processes is very slight, and in muscular reaction, apperception seems to be entirely absent. Yet the analysis of such a simple action as responding to a pre-arranged stimulus, reveals a very great complexity on both the mental and the physical sides.

In simple reactions, there is, however, little which can entitle them to be termed intellectual processes. It is not until we complicate the reaction in various ways that we find anything approaching to co-operation of the higher mental processes. Such reactions are known as complex or composite reactions; they correspond to our arcs of the second level. The subject may be instructed to *recognize* what he sees or hears, before reacting to it. By subtracting the time taken, from the subject's sensorial reaction time, we get the Recognition Time. In such experiments we are laying emphasis on the mental aspect. By means of a rapid drop shutter with an aperture, various objects, such as letters of the alphabet, or digits, or colours, can be shown, which the subject must recognize before responding. The recognition time for small words has been found to be similar to that required to recognize individual letters. Slightly more complicated are discriminative reactions, where a series is drawn up consisting of two colours, and the subject has to discriminate which colour is shown before reacting. By subtraction we obtain the "discrimination time," which is about 30 σ longer. Reaction involving choice may be performed by giving the subject two reaction keys. If he sees green he is to react with the right hand, if red, he is to react with the left hand. In the case of discrimination only he is enjoined to react if red appears, and not to react if green appears. Thus in both cases the subject has to discriminate what colour is presented to him, but in the case of choice he has to react towards each in a slightly different manner. The time

registered for such reactions is considerably longer than discrimination times, and it increases steadily the greater the number of stimuli employed, and the greater the number of reactions. A five-fingered reaction key may be used, and the subject may be requested to react with a different finger to each of five different colours, or two five-fingered keys may be used and all ten fingers utilized. By this means, it has been often suggested, we measure rapidity of thought, but such acts of discrimination and choice are vastly different from our ordinary acts involving discrimination and choice. For in these experiments the mode of response is determined beforehand, and the stimuli are seen over and over again. Further, the reaction, as practice proceeds, tends to become almost automatic, and in choice reactions the movements of a particular finger become so closely associated with the perception of a specific colour, that the response takes place immediately without requiring any mental process of choice.

Discrimination and choice experiments may be carried out quite simply by using a watch only. If we arrange the individuals, who are to participate, in a circle as before, we can find the time taken to discriminate a touch stimulus. For the simple reaction to touch the individual had merely to pass on the stimulus whenever he received it. To find the discrimination time, each individual touches the individual in front on the right or left shoulder, and whenever the latter apprehends which shoulder has been touched, he passes on the stimulus to the person in front of him. Each individual must arrange beforehand what shoulder he is going to touch of the individual in front of him, so that no time will be wasted once he has perceived the stimulus. By averaging the time as before, the average discrimination time for each individual can be obtained.[1] Choice reactions can be carried out in much the same way. This time, if the stimulus is a tap on the right shoulder, the individual must respond with the right hand, if the left shoulder with the left hand. Discrimination must take place first, and as a result of discrimination the appropriate response is chosen.

Associative reactions may be regarded as belonging to the third level of action. The subject sees or hears a word, and he is asked to respond by the first word or idea which it suggests to him. The time between the presentation of the stimulus

[1] This is not a very satisfactory experiment since we have no means of securing that discrimination shall take place.

and his reply is known as the association time. The experimenter may press down a morse key when he shows the word, and the subject replies by lifting his finger off a second morse key simultaneously with articulating the word.[1] Three types of association experiments can be carried out; the association may be entirely free, or wholly, or partly constrained. If free association is employed, the subject is at perfect liberty to reply with any word. When the association is wholly constrained, only one answer is correct. The subject may be asked to perform a simple mathematical calculation, such as the addition of two numbers, or to name the month preceding the one shown, or to translate the stimulus word into a foreign language, or to name the capital of a country. If the association is only partly constrained, more than one answer may be correct. An adjective may be shown, and the subject asked to supply a suitable noun, or a whole may be shown and the subject asked to name a part of that whole. Association times are considerably longer than the other types of reaction time, and they also show greater variety. In free association, if the word given is associated with some intense emotional experience of the subject, the reaction time may be very long. This is the basis of Jung's Association Method, as we shall see later. As a general rule free association times are longer than the times required for constrained associations, but this depends to some extent on the familiarity of the association in the case of the latter. Free association experiments may be carried out with the circle as before, each response serving as the stimulus word for the individual next in the chain.

The muscular reaction, the discrimination and choice reaction, and the association reaction, correspond approximately to the three levels of the nervous system. They illustrate the greater complexity of mental process as we pass from the lowest to the highest arcs. It is sometimes said that in the case of association experiments we are measuring the rapidity of thought. The statement requires some qualification. We are really experimenting only on the minimal operations of thought, the suggestion of one idea by another idea. Yet this is one of the chief methods by which the thought processes are studied in the psychological laboratory.

[1] This is a rather crude method, but association times are fairly long. For accurate work an exposure apparatus, a chronoscope, and a sound or lip key are necessary. See also p. 21.

When very accurate measurement of reaction times is desired, we employ some type of chronoscope, and usually the Wheatstone-Hipp, as far as the psychological laboratory is concerned. This records thousandths of a second. The clock-work goes independently of the hands, and the giving of the stimulus starts the hands, while the making of the response stops them. The time is obtained by taking the difference between the reading of the chronoscope before and after the experiment.

In all reaction time experiments there ought to be considerable practice on the part of the subject before we begin to keep the record of times. The experimenter should give the warning "ready" about two seconds before presenting the stimulus. Throughout the experimental series the subject must try to introspect. Mere quantitative results are of little value. The subject may find introspection difficult at first. In that case it may be wise to "fractionate" the introspection, that is, observe separately different phases of the whole process. Three phases may be distinguished, the phase immediately preceding the reception of the stimulus, when the mind is full of the expected idea of the stimulus, the phase involved in the actual carrying out of the response, and the phase immediately after the response. It must be clearly remembered, however, that these phases are not separate or even sharply defined, but together form one unified process.

CHAPTER IX

WORK AND FATIGUE

THE investigation of fatigue was one of the earliest practical problems to be undertaken both by the physiologist and the psychologist. The physiologist observed the isolated muscle and nerve, and from his studies much valuable data have been obtained. It has been found that when energy has been expended in work, absolute fatigue ensues when all the glycogen or the energy-producing material of the muscle is used up: and that no fresh activity will be possible until there is a fresh supply. It is rare, however, for such a situation to arise, unless the muscular work is exceedingly intense, for the supply of glycogen is usually prevented from becoming totally exhausted by certain other factors which act as safeguards. One of these is the delicate "end-plates"—the termination of the nerve fibres in the muscle. These become fatigued before the muscular tissue itself becomes totally exhausted. Another safeguard is due to the accumulation of the bye-products formed in all muscular activity. In a state of activity, toxic or poisonous substances such as lactic acid and carbon dioxide are produced. When the activity is not too continuous and severe, these are eliminated as quickly as they are produced. But again, if the muscular activity is too intense, these bye-products accumulate much more rapidly than they can be eliminated, and "choke up" the working areas, thereby inhibiting action. A third safeguard is due to the action of the central nervous system, which, as we shall see later, has considerable influence over the muscular system in preventing fatigue.

A difficult problem presents itself from the outset in all study of fatigue. What is its nature? how may it be defined? We may describe fatigue in either of two ways, either subjectively or objectively. Subjectively, fatigue may be defined as a characteristic mass of sensations and feelings, involving a state of

consciousness of unpleasant affective tone. This subjective feeling is simply the effect of the physiological state of the organism, and has different degrees of intensity ranging from mere boredom to sheer exhaustion. The subjective element represented by tiredness or weariness is the *feeling* which sometimes serves as an indicator of the objective state of fatigue. But to define fatigue subjectively is not entirely satisfactory, for an individual may have a very pronounced *feeling* of fatigue, and yet his output of work may remain unimpaired. In fact, the subjective experience may be felt on the commencement of any piece of work before it is possible for the energies to have become depleted. This simulated fatigue is due, probably, to dislike of, or disinclination for, the work in hand, and a fresh incentive may be all that is necessary to evoke renewed energy. On the other hand, however, an individual may be near the point of exhaustion and yet experience no corresponding feeling. This is a dangerous condition, since the subjective criteria give no index as to the real state of the organism, and the individual may work on with injurious effects to himself.

If we define fatigue in objective terms, we can do so on a more reliable basis, but even then, the result is again not wholly satisfactory. Fatigue is the state in which the organism is exhausted and requires rest. Accordingly it may be described as a condition of lowered efficiency due to expenditure of energy on work, or as a decreased capacity for work. This lowered efficiency or decreased capacity may be tested by the production or output of work. In a state of fatigue, the output is diminished, or the quality is impaired, or both are affected. Objectively then, we have to define fatigue in terms of output. This definition is not free from error, for as Myers points out in *Mind and Work*, fatigue may produce a general excitement with extravagance in the expenditure of energy, resulting in increase rather than decrease of output.

As a mental phenomenon then, fatigue occurs as this subjective feeling of tiredness. As a physiological phenomenon it is a state of lowered efficiency of the organism shown by diminished output.

A further question arises—is it possible to separate out mental from muscular fatigue or mental work from muscular work? Can the one take place independently of the other? If we consider an instance of pure mental work such as mental multiplication, or the multiplication of numbers without visual

or written aids, then, as Hollingworth points out,[1] the extreme state of attention necessary is accompanied by sense-organ adjustment and tension of most of the bodily muscular system. That is, it seems impossible to have mental activity which does not produce muscular activity as well. If, by mental fatigue, we mean the expenditure of energy and accumulation of poisonous substance in the central nervous system, and by muscular fatigue, the expenditure of energy and accumulation of poisonous substances in the muscles, then it seems impossible to have mental fatigue which does not involve muscular fatigue, or muscular fatigue which does not involve mental, for all muscular activity involves the nerve centres, and all mental activity causes some contraction or tension in various groups of body muscles. As one of the authors has pointed out elsewhere,[2] one of the most interesting symptoms of on-coming mental—as of on-coming muscular—fatigue is loss of control over the direction of the nervous impulse. In the case of mental fatigue this shows itself in a wandering of the attention and an inability to keep the mental activity to the desired channel; in the case of muscular fatigue in the spread of excitation to muscles other than those required.

It is impossible, accordingly, or at least inadvisable, to study either mental or muscular fatigue alone, to the neglect of the other. The behaviour of the single detached muscle which the physiologist observes has certainly yielded invaluable results, but the conditions under which it is observed are quite different from those which exist when it forms a part of an intact organism. For as everyone knows, to take one instance only, the amount of work an organism is capable of performing depends largely upon the mental condition at the time. Nevertheless, for practical purposes, work may be regarded as either predominantly muscular, or predominantly mental. These two classes we shall consider in turn.

The study of muscular work has been carried out by means of the ergograph. There are different makes of ergograph, but all embody the same general principles. Those most extensively in use are Mosso's and Kraepelin's. The apparatus is so devised as to measure rhythmical muscular contractions which can be continuously recorded. The "work" is usually carried out by the middle finger of one hand, but other

[1] *Applied Psychology*, p. 142.
[2] Drever, *The Psychology of Industry*, p. 65.

ergographs have been devised which test different muscles of the body. Arm and hand are clamped to prevent movement, the forefinger and third finger are fixed in metal caps, and only the middle finger is left free to move. This is inserted in a leather attachment or brass cap from the end of which a weight depends sufficiently heavy to put some strain on the finger. The finger is then flexed and extended regularly to the beats of a metronome, which is set at 60. A complete contraction and extension, accordingly lasts two seconds. The movements of the finger are communicated to a lever which records the height of each contraction on a rotating smoked drum. Such a graphic record or fatigue curve is known as an *ergogram*. The total distance through which the weight has been lifted up in a series of contractions can be ascertained from a travelling scale which moves with each pull on the weight; or if the weight is lifted higher each time, and does not return to its original starting place, as happens with some ergographs, then the total height can be easily obtained by measuring the height at which the weight is finally left.

Many interesting facts have come to light in ergographic work, and the reader will find a wealth of information in Mosso's own book on "Fatigue," which forms the pioneer study in this subject.

If the contractions are continued long enough, a point is reached at which the individual is unable to lift the weight any longer. Complete fatigue has set in, and before another contraction can take place, the muscle in the finger must be rested. The fatigue, however, is only fatigue to certain conditions. If the weight be lightened, the finger becomes able once more to flex and extend as before, lifting the weight maximally each time, until the onset of fatigue occurs again under these new conditions. The first ergogram is accordingly not so much a graph of the course of general muscular fatigue as a record of the onset of fatigue towards a special set of conditions.

When a muscle is voluntarily contracted, impulses are sent along afferent nerve fibres to a nerve centre, the effect of which is to inhibit the nerve impulses which would normally pass down and produce further contraction of the muscle. The nervous system, by its control over the muscular system, prevents it from becoming fatigued. The contractions become gradually and gradually smaller in extent, and the inhibition becomes so great that no amount of volition can overcome it

and produce further movement in the muscle. It is evident, therefore, that the muscle itself is not fatigued; it is merely inhibited by the central nervous system from further action so long as these particular conditions exist, namely, lifting rhythmically a given weight. That is the reason why a fresh ergogram can be obtained, if a lighter weight is substituted. But even if the *same* weight is retained, muscular contractions can be obtained if the muscle is not contracted voluntarily but is stimulated through the nerve by means of a faradic current. In other words, central nerve control has set up inhibitory processes which are a safeguard against the evil effects of continuous muscular excitation.

The introduction of systematic pauses into ergographic work has been the subject of much study. As we have already indicated, a fatigue effect is soon produced if a weight is lifted continuously. But it is an interesting fact that if a pause is allowed after every contraction of the finger, no fatigue results in a long period of work. In one experiment [1] in which the lifted weight was 6 kilograms, a rest pause was given of ten seconds after every contraction. The result was that the subject could continue lifting the weight indefinitely, and no fatigue was produced. When the rest interval was reduced to two seconds instead of ten, the fatigue set in after 30 contractions, or at the end of a minute, the subject being unable to produce any further movement. In fact, before the fatigue effects had completely gone, a rest of two hours was required.

The length of the necessary rest pause does not vary directly with the number of lifts. For example, we might imagine that after half the number of contractions, half the period of rest would be found sufficient. But such is not the case. Although 30 contractions require to be followed by a two-hours' rest in order to eliminate all fatigue, 15 contractions, using exactly the same weight, only necessitate a pause of half an hour. That is, that after such an interval, a second set of contractions as good as those recorded the first time would be made, and so on indefinitely. Or, if we express the result differently, if a certain amount of work requires a certain amount of rest in order to recover from the fatigue produced, then twice that amount of work requires more than twice the amount of rest.

Let us deviate for a little and consider the far-reaching

[1] *Vide* Muscio, *Lectures on Industrial Psychology.*

effects of this result as applied to industry. Suppose we follow Muscio [1] again and consider the purely hypothetical case which he discusses. The work in a certain factory in an eight-hour day consists in lifting weights with the middle finger. One worker adopts the first method, 30 contractions followed by a two-hour's rest. The odd minutes may be neglected. In an eight-hour day he will have four work periods, giving a total number of contractions of 120. A second worker adopts the second method, namely, 15 contractions, followed by a thirty-minutes' rest. This will give eight working periods, yielding a daily total of 240 contractions. This second method produces exactly double the number of contractions, assuming that the contractions are all equal. The increase in output is due entirely to the better distribution of work and rest. If a third worker were to adopt a ten-second pause after every single contraction, the whole (contraction and pause) occupying twelve seconds, his output in an eight-hour day would be far greater than the other two, and would reach no less than 2400 contractions.

These results are only approximately correct, and the case is a purely hypothetical one, but the results clearly show the principle underlying the effect of pauses.

The Work Curve.—Suppose we consider, instead of the ergograph, a test which is more mental in character, and investigate more fully what is known as the "work curve." If we take the cancellation test, the method of obtaining a work curve is very simple. The subject is given a page of print and asked to cross out all the a's thereon. The experimenter, using a stop-watch, gives a signal to the subject every minute, or every two minutes, or at some other prearranged time interval, whereupon the subject indicates by a cross on the paper the point at which he has arrived. Thus, by counting the number of cancellations made per minute in a continuous experiment, the result can be plotted and shown in graphical form. At first glance, the work curve presents a somewhat irregular appearance. These irregularities are due to spurts on the part of the worker. Usually an *initial spurt* is shown; the subject starts at the beginning of the task with a speed which he is unable to continue for long, and which he has to slacken. Then there may be a *final spurt;* that is, if the individual is aware that he is nearing the end of

[1] *Vide* Muscio, *Lectures on Industrial Psychology*, p. 84.

his task, an additional effort is made and the output is increased. Thirdly, *intermediate spurts* may appear throughout the curve; these can be traced to various causes. They may be due to wandering of the attention, or the idea may pass into the worker's mind that he is not doing as well as he can, or a poor result may be followed by a better one, a result often apparent in work with the ergograph. If, however, we neglect these intermediate spurts, and smooth the curve, it takes on a regular shape which is typical of all work curves, both muscular and mental. The initial spurt at the beginning is followed by a decided fall in the curve. Then, as the practice effects begin to tell, the curve commences to rise again, rapidly at first and gradually more slowly until the maximum output is attained. The maximum is maintained for a time, then the curve begins to fall. This is caused by the onset of fatigue which produces a general diminution in output until the final spurt, if any, makes its appearance.

The rise and fall in the curve are principally due to the factors of practice and fatigue, the one causing the rise, the other producing the fall. Certainly, the practice effect is increasing, even when fatigue is present, but the fatigue counterbalances the practice, and it is at the commencement that the practice effect is most noticeable. Fatigue, of course, may increase the work quantitatively, but it invariably decreases it qualitatively. In addition to these two factors, other two are of importance, *incitement* and *adaptation*. The factor of incitement or warming-up is shown at the beginning of any piece of work and combines with the practice effect in causing the steep rise; it is also present in starting again after a pause. The machine, as it were, has grown cold and requires warming-up before maximum efficiency can be obtained. Adaptation is rather difficult to distinguish from incitement. It consists in adapting ourselves to the piece of work in hand, in fact, to settle down so that we are free from all distraction.

Now, what is the effect of introducing a pause into the work on these four factors, and how will it modify the work curve? In the first place the fatigue is eliminated which is the main result. But a loss of incitement and a loss of adaptation take place, and in the case of the beginner there is a loss in practice.

If the pause is too short, it will not compensate for the losses in incitement and adaptation: if it is too long the practice effect will be partly eliminated, and the general working efficiency will be impaired. Hence it is desirable to find a pause

which is neither too long nor too short, namely, the *most favourable pause.* On the other hand, the precaution must be taken not to insert pauses too frequently. This may be detrimental to efficiency, particularly if a long warming-up period is the general rule.

One excellent illustration of the benefit to be derived from the introduction of rest pauses is shown by the results of a recent investigation.[1] The occupation was that of folding handkerchiefs. Before pauses were systematically introduced, the employees worked steadily on without a break, but could take intervals for rest if they so desired. This rarely happened, however, for the girls were paid for work done. After the work had been carefully studied, certain recommendations were made, such as raising the height of the work-table to avoid undue fatigue. But more interesting was the introduction of pauses into the work. Every hour was divided into six-minute periods. In any hour, the worker remained sitting for the first four of these periods (twenty-four minutes). During this time she worked five minutes and rested one. Thus four minutes out of twenty-four were spent resting, and these rests were taken sitting before the work-table. For the next twelve minutes, the girl stood to do her work, observing the same routine of work and pause as before. During the next three periods of the hour (that is, eighteen minutes), the operator could sit or stand, but kept again to the same routine of five minutes' work, one minute rest. For the last six-minute period, the girl did no work but could do anything she desired. The result was that the output was three times as great as before, and the girls felt considerably less fatigued at the end of the day. Further, the monotony of the work was considerably lessened.

It must be remembered that each individual has a different type of work curve; some require long periods of adaptation, others adapt themselves quickly to new conditions. Meumann claims to have found three types of workers amongst adults. The first type reaches maximal efficiency quickly and then the work gradually decreases in efficiency, and fatigue sets in rapidly: the second type requires a definite period of time before the maximum is reached, and fatigue is not so rapidly produced: the third type has its maximal efficiency displaced towards the conclusion of the work and requires continuous work over a long period of time before the maximum is reached. Individuals

[1] Muscio, *Lectures on Industrial Psychology*, p. 179.

belonging to this class seem able to withstand fatigue for a considerable time. All these factors require to be kept in mind when deciding on the length and frequency of pauses. The introduction of pauses, accordingly, must not be made haphazard, but requires, in every individual case, systematic investigation and experiment.

Methods of investigating Mental Fatigue.—Two methods of procedure in investigating mental fatigue have evolved, and these have been extensively used in the field of education. The methods are known respectively as the *Interpolation* method and the *Continuous* method.

In the interpolation method, the mental work on which the subject is engaged is interrupted at regular intervals, say every half-hour, and the subject is submitted to a certain test, different from the work on which he is engaged. His mental efficiency is calculated by comparing the efficiency with which the interpolated test has been performed at these different times. Interpolated tests are usually indirect tests, that is, tests of some subsidiary change brought about by the work, but direct tests of mental efficiency may also be employed. In the continuous method, the subject is engaged in a definite piece of mental work and the work itself may be tested directly as regards both quantity and quality at prearranged times. Fatigue causes the quantity to diminish and the quality to deteriorate, the latter usually indicated by an increase of errors. The diminution in the mental efficiency is considered an indication of fatigue.

Let us consider indirect tests in the first instance. The most famous test historically is that of the determination of the spatial threshold. For a long time, extravagant claims were made as regards the ability of this test to give a good indication of the presence of fatigue. The result is complicated, however, by so many other factors, and the threshold varies so considerably with different individuals, that it is extremely difficult to obtain data which are at all comparable. It has the one advantage that quantity alone is measured, and that quality is not involved. Another method sometimes used was to compare the individual's sensitivity to pain in normal and in fatigued states. But this again proved unsatisfactory, because it is not at all certain whether fatigue causes sensitivity to pain to increase or to diminish. The ergograph was also thought to give good infor mation of the presence of mental fatigue, and ergographic test were instituted after a period of severe intellectual strain. This apparatus, however, is rather a test of muscular fatigue, and as

has already been demonstrated, tends to develop muscular fatigue, which is purely local in character. The tapping test is another device employed. The rate of tapping obtained in a fatigued state is compared with the normal rate of tapping. The reversible-perspective test has also been used. This consists of a figure, usually of two rectangles, one within the other, and their corresponding angles joined. This figure can be seen in two ways, with the one or the other of the two sides towards the observer, giving now a convex, now a concave effect. It is impossible to maintain the one aspect of the figure for any length of time, for in a few seconds the figure becomes reversed. The subject, although unable to prevent the reversal, is able to control the rate of reversal, and it is control which forms the basis of the test. When the individual is fatigued the control is impaired, and the normal rate of reversal is diminished. Further, the interval of time which occurs between each reversal is decidedly lengthened. This would undoubtedly be a satisfactory test of fatigue but for one reason and that a serious one, namely, the lack ot objective control, for full reliance must be placed on the trustworthiness of the subject.

The great disadvantage of the interpolated test is that a change of task involves a change of interest, which is apt to cause a diminution of fatigue.

The direct tests are more reliable than the indirect tests. They possess, however, one considerable disadvantage, incident to the majority of mental tests, which lies in the difficulty met with in evaluating results.

Direct tests may be divided into two kinds. On the one hand, as has already been suggested, the work itself may be tested at different intervals in a certain period of time. The first twenty minutes may be tested and compared with the last twenty minutes, or special tests may be given which are similar in nature to the work causing the fatigue. The chief direct tests belonging to the second category are four in number. The ordinary dictation test appears to give valuable results. In one instance reported by Friedrich the number of spelling errors of one class before lessons began in a prescribed piece of dictation was 40. The total rose to 70 after the first hour of work, to 120 after two hours, to 190 after three hours, clearly demonstrating the presence of fatigue. The chief difficulty in such a test lies in the standardizing of results, and in equating satisfactorily one spelling error with another. The cancellation

test has also proved of utility in this connection. In such a case, the efficiency is measured by the amount of matter read, and the number of times the subject has omitted to cancel the letter. Unfortunately, this test involves muscular fatigue, and is one which is considerably affected by practice. Ebbinghaus' completion test is another test which has given satisfaction. A piece of prose or part of a story is set before the subject, but certain words or phrases are omitted. The subject is required to fill in these blanks. The fatigue is indicated by the amount read, and by the number of blanks filled. Finally, simple addition and multiplication tests may also be utilized.

These direct tests can all be applied as group tests, the indirect tests are generally used as individual tests.

Time and Motion Study.—Time and motion study properly belongs to the sphere of industrial psychology, but as it had its origin in the laboratory and developed out of a study of reaction time and fatigue, a brief account of it is interesting as an example of the application of experimental psychology. Motion study aims at eliminating unnecessary and wasteful methods and instructing the worker in what we might call a "shorthand method" of working. All useless movements are dispensed with, thereby reducing fatigue, and the most efficient co-ordination of movements is investigated, the aim being to obtain the maximum of work with the minimum of effort on the part of the worker. The guiding principles of motion study are threefold. First, the elimination of useless movements; second, the combining of separate movements into a single circular movement, based on the fact that one uninterrupted circular movement is less fatiguing than two disconnected movements; third, attention is paid to rhythm. It is less fatiguing to perform an act rhythmically than to perform it as an irregular series of jerky movements. This is particularly the view-point of British psychologists as represented by Eric Farmer. Farmer regards time and motion study, not from the point of view of speed (as do the American investigators, Taylor and Gilbreth), but from the ease with which the worker can perform the movement. He endeavours to arrange a task so that it will be in keeping with the natural rhythm of the worker, that is so that it should be in accordance with physiological and psychological laws, thereby using body and mind as economically as possible.[1]

[1] *Report of the Industrial Fatigue Research Board*, Number 14, General Series Number 5.

CHAPTER X

SUGGESTION AND SUGGESTIBILITY

WE must in the present chapter anticipate, to some extent, the discussion of images and ideas. This is unavoidable if suggestion is to be discussed in close connection with the psychology of action, where it really belongs. Suggestion is usually defined as the mental process which results in an individual accepting without logical grounds, and acting without deliberation upon ideas conveyed by the words, attitudes, or acts of other people. This definition would seem to imply a close relationship to *ideomotor action*, and therefore to the ideational level of mental life. But, although it undoubtedly covers most of the main phenomena, it is really too narrow, and there are two respects in which it must be extended. In the first place, the "idea"—which itself must be taken in the widest sense—may come from within rather than from without. This is known as *auto-suggestion*. And it may further have as its source objects in the environment, perceptually apprehended, as well as other people. All that is necessary in that case is that the object should be normally associated with some kind of action. In the second place, "acting" must be taken to include much more than overt action. For example, the taking up of an intellectual or emotional attitude, the adoption of an opinion or belief, and even, in extreme cases, the having of a perceptual experience, may be the outcome of suggestion.

Before considering suggestion specifically, something must be said regarding *ideomotor action*. Action which follows directly and involuntarily on the thought or idea of the act is *ideomotor*. A distinction is sometimes drawn between *sensori-motor* and *ideomotor*, but there is really no sharp line of demarcation, except that in the former case action is directly determined by sensory stimulus. There are, in fact, all gradations between involuntary action, excited directly and immediately by a

sense stimulus, and an act which takes place involuntarily as a result of the thought of that act passing through the mind. Midway between these two extremes is the act which may be described as unconscious imitation, where, in watching with highly concentrated attention other people acting in some way, we suddenly find that we ourselves are performing, or have performed, unintentionally, some one of the acts we are observing. The notion of a sharp line of demarcation really arises from the older analytical psychology of the thought processes, which regarded "ideas" as separate, purely mental, entities. This view falsifies the facts in two respects. On the one hand, it treats a partial aspect of a complex process—the complex process being the behaviour of an organism—as if it were a whole in itself, separable, if not separate, from the rest of the mental life. This is not the place to deal with this point. On the other hand, it assumes that a thought or idea is purely mental. It is safe to say with the behaviourists that no idea we ever have is purely mental. In most cases ideas passing through our minds are at least *named*. This means that in thinking we carry on a kind of suppressed conversation with ourselves, and this suppressed conversation implies, in probably every case, the initiation of the articulatory processes involved in actually speaking the words. For example, if we think of a word like "babble," we feel a kind of tremor in the lips. This fact is taken advantage of in certain experiments where we wish to eliminate the auditory and motor imagery of words. The plan adopted is to ask the subject to keep on articulating some such sound as "la." As a matter of fact this does not wholly eliminate the possibility of auditory and motor verbal imagery, but it is quite certainly a great impediment.

Every thought of movement involves the beginnings of the actual movement, that is, the first muscular contractions in making the movement. What of ideas that are not ideas of speech or movement? The fact is, every idea we have, whether an idea of movement or not, involves movement of some kind. We think of a landscape we have seen, and careful observation will tell us that there are incipient contractions of the eye muscles of the same kind as those involved in actually seeing, and allowing our eyes to rove over the landscape. Illustrations might be multiplied indefinitely.

Even this is not the whole of the truth. It is largely by means of this motor factor that we control the course of our own

thought. We get control of a movement by getting the *feel* of the movement. In thinking of the movement, we think of its *feel*, and this means the beginning of the movement itself, and the movement is made. Take a longer chain. The child learns to make the movements involved in throwing a ball. He learns also, let us say, to make the sound "frow" in connection with the movement. He can now initiate the movement by thinking of the word, and another person may cause the movement to take place by speaking the word, and so on.

When the idea of an act immediately realizes itself in the act, then we have the kind of action called *ideomotor*. Many of the actions designated "impulsive" are of this order. If what has just been said is true, it may be asked why all actions are not ideomotor. As a matter of fact all actions are up to a certain point. What usually happens is that, before an act can be realized, the situation calls up other opposing ideas, and action is suspended until we have, as we say, made up our minds what to do. If in any way these opposing ideas are prevented from rising in the mind, or anticipated by action, then the movements which are initiated with the idea complete themselves in the act. One marked feature of suggestion is that, under its influence, opposing ideas are prevented from coming into the mind. In this respect the phenomena are continuous with those of ideomotor action.

Three simple experiments will enable us to make the transition to suggestion phenomena. The first is Coué's well-known experiment. If an individual clasps his hands together, holding them up in front of him, and keeps saying with conviction, "I can't unclasp them. I can't. I can't," then he really cannot unclasp his hands so long as he keeps asserting his inability and thinking it; and very frequently he finds that he cannot unclasp them after he has ceased to assert his inability, the condition of inability still continuing. The second experiment is likewise fairly well known. It is the experiment with "Chevreul's pendulum." Make two chalk lines crossing one another at right angles on the top of a table. Tie a button to a thread about 15 inches long. Let the subject hold the end of the thread so that the button is suspended over the intersection of the two lines and a few inches above the table. Now tell the subject to let his mind dwell on one of the lines, his attention passing along it from one end to the other. The button will at once start to swing along that line, and the swings may attain a

considerable amplitude. Let the subject next change the direction of his thought and attention to the other line, and the pendulum, too, gradually changes its direction of swing, till it swings along the other line. The third experiment is a well-known parlour game, and does not require to be described. It is the game of so-called "thought-reading," though a better name would be "muscle-reading." The thought-reader is led by his guide to the hidden object, because his guide's whole attention is given to the object and its hiding-place, and he accordingly unconsciously tends to move towards it, and to resist any movement in the wrong direction.

These three experiments all illustrate the phenomena of what has been called *auto-suggestion*. They are somewhat more complex than the phenomena usually ascribed to ideomotor action, but obviously of the same order. In all three cases ideas realize themselves *automatically*, or, if it is preferred, *subconsciously*. An illustration showing still more complex phenomena of the same order might be cited. That is the census tabulation case, fully described by Jastrow,[1] whose description we shall follow. In 1890 the United States Census Office adopted a new system of tabulating the returns. It was from the outset assumed that the work was complex and difficult, and this furnishes the key to the attitude with which it was undertaken by the staff. The family schedules were edited by clerks in batches of twenty, with an instructor for every batch. After five weeks of this work, the most intelligent of the clerks were put on the special punching machines. It was considered that 550 cards represented a day's work. Two weeks passed before any clerk reached this total. All the clerks were now set to work on the machines, and in another two weeks most of them reached 500 cards a day. At this stage a roll of honour was posted daily, the result of which was that in another week the clerks were doing from 600 to 1500 cards a day, but with so great nervous strain that complaints were made to the authorities, and the posting of records forbidden. Two hundred new clerks, who had no experience with the schedules and had never seen the machines, were now added to the staff, and scattered among the clerks already at work. Their lack of experience was more than compensated by the fact that they were not under the influence of the suggestion that the work was complex

[1] *Fact and Fable in Psychology*, p. 303.

and difficult. On the contrary they saw their fellow-clerks working away easily and rapidly. The consequence was that in three days several of these new and untrained clerks reached the 500 mark, in a week nearly all, and before the work was finished one of them reached the figure 2230. So much for the influence of the idea that the work to be done was complex and difficult, on the one hand, and that it was simple and easy on the other!

The whole range of the phenomena producible by suggestion is best seen with subjects in the condition known as *hypnosis*, or in various *hypnoidal states*, closely allied to it. The hypnotic state itself is produced mainly by suggestion, and one modern school of psychologists would define it simply as a state of exaggerated suggestibility artificially induced. Though hypnotism cannot be regarded as belonging legitimately to the phenomena that can be, or ought to be, studied in the ordinary psychological laboratory, nevertheless, we may indicate the various types of suggestion phenomena that may be produced under its influence, all the more because practically every one of the phenomena can be paralleled with suitable subjects, without any hypnosis, as that is generally understood. The phenomena can be classified under four heads:—

1. Phenomena involving the control of the subject's voluntary musculature. Not only can the operator or experimenter control (within limits) the subject's external behaviour, but he can control the subject's voluntary muscles independently of the subject himself, by producing, for example, inability on his part to execute ordinary movements that he wills to perform, producing, that is, a temporary paralysis.

2. Phenomena involving control of the senses and the memory. Hallucinations, both positive and negative, can be readily produced. In positive hallucinations the subject has a sensory experience which has no objective basis; in negative he fails to apprehend stimuli which are affecting his sense organs at the moment. In the latter case we have artificial anæsthesia, and artificial anæsthesias may be induced in any one of the sense departments, vision, hearing, touch, even pain. The memory can be controlled in an analogous way. For example, the subject may be made to forget his own age or his own name.

3. Phenomena involving control of the involuntary musculature and the glands. These phenomena might be said to verge on the abnormal, and are only producible with highly favourable

subjects, unless they are produced indirectly by first evoking emotions.

4. Phenomena involving structural or organic changes. This final group of phenomena must be treated with considerable caution. The evidence is such that there can be no reasonable doubt that phenomena such as the production through suggestion of blisters on the skin do occur, though we are, as yet, unable to understand how they occur.

Testing Suggestibility.—In order to determine with any degree of accuracy the conditions under which suggestion operates most favourably in the normal state, we must have some means of measuring a subject's suggestibility. Several methods of measuring suggestibility have been devised by investigators. One of the simplest methods is due to Binet, and has been incorporated in the Binet-Simon series of mental tests, usually spoken of as the Binet Scale, of which more hereafter. In this case a subject's suggestibility is tested by a "line trap." Two lines of different lengths are shown the subject, and he is asked: "Which of these lines is the longer?" On the first occasion the lines are 4 cms. and 5 cms., on the second 5 cms. and 6 cms., on the third 6 cms. and 7 cms., and on all other occasions 7 cms. and 7 cms., that is, equal. In the actual Binet test the "trap" is only given three times, but there is no reason why the experimenter should not continue to repeat it, as long as there is response to the suggestion. A rough measure of an individual's suggestibility would be the number of times he continued to find one line longer than the other, after the two equal lines began to be presented. A more elaborate test of the same type may be carried out either with progressive lines or progressive weights. As described by Whipple,[1] the test with progressive lines would be carried out as follows: Lines are drawn on a strip of paper fastened on a revolving drum. There are 20 lines in all. The first four are 12, 24, 36, and 48 mm. long respectively; the remaining sixteen are 60 mm. long. The lines begin at varying distances from the left-hand margin of the paper, and are 2 cms. apart. These lines are shown to the subject one at a time through a horizontal slit in a sheet of cardboard. The instructions are that the subject should take one look at each line, and then attempt to mark its length from the left-hand edge of a sheet of squared paper

[1] *Manual of Mental and Physical Tests*, vol. ii., p. 237.

with which he is provided. The drum is turned so as to expose the first line, and then moved forward so as to conceal the line while the subject marks off its length. Then the second line is shown in the same way, and so on. If necessary the test can be continued beyond the twentieth line by turning back the drum without the knowledge of the subject to the fifth line. For a measure of suggestibility we take the number of lines drawn longer than the fifth line. With progressive weights the test is carried out, *mutatis mutandis*, in a similar way. There are fifteen weights of precisely the same size and appearance. These are arranged in a row, No. 1 to No. 15, with No. 1 at the left. The first four weights are 20, 40, 60, and 80 gms. respectively; all the others are 100 gms. The subject has to say whether a weight is "heavier," "lighter," or "the same" as the one lifted before it.

The *size-weight illusion* has also been made the basis of a measurement of suggestibility. If we take two objects—say two round blocks—of the same weight and appearance, but differing greatly in size, the smaller will seem, as we have already seen, much the heavier, because the size *suggests* the amount of muscular effort to be put forth in each case, and the larger object rises with much greater ease, the smaller with much greater difficulty, than expected. By providing a series of round blocks of a size midway between the two original blocks, all of the same shape, but graded in weight through a fairly wide range, we can find the block that seems to be of the same weight as each of the original blocks respectively. The difference between the weights of these two blocks may then be taken as a measure of the suggestibility of the subject who has selected them. Thus, if the standard weights are each 55 gms., and the middle-sized blocks range from 15 to 80 gms., the subject might estimate the larger block as equal to a middle-sized block of 20 gms., and the smaller as equal to one of 70 gms. The suggestibility of the subject would be given by the difference between 70 and 20, that is 50.

The production of illusions or hallucinations by suggestion has indicated yet another method by which suggestibility can be measured, at least roughly. Illusory warmth was first employed in the Yale laboratory by Seashore, working on lines that had been suggested by Scripture, and the method adopted remains the most satisfactory of the methods of this type. A resistance wire is arranged so as to be perceptibly heated in

from eight to ten seconds by passing through it an electric current. To begin with the current is passed through the wire, and the subject, holding the wire, soon feels objective warmth. This is repeated two or three times. After that the circuit is broken unknown to the subject. The switch is closed ostentatiously as before, and the experimenter takes the time for the appearance of the illusory warmth in the wire. The measurement of suggestibility is given by the relative number of times the subject reports warmth when there is no current in the wire.

All these methods show increasing suggestibility with age up to nine or ten, after which there is a gradual falling off, and at all ages girls show greater suggestibility than boys. It will be noted, however, that the personal factor does not come in, except indirectly, in any of the tests. This is unfortunate, because this is the most important factor of all, as far as the suggestion of everyday life is concerned. Still more unfortunate is it that, when the personal factor enters, as in the experiment about to be described, its influence is so variable and incalculable that the idea of measurement must be practically abandoned, except for measurement roughly and in the mass.

The "Aussage" Experiment.—Much experimental work has been done during the last quarter of a century on the psychology of testimony, work which has important practical bearings in many directions. The idea of testing the ability of an individual to give a reliable report of an experience appears to have originated with Binet.[1] The ability is a somewhat complex one, depending as it does upon ability to observe, to interpret, to retain, to recall, and to relate. Apart from the testing of the range and character of observation, with which we are not at present concerned, fidelity and adequacy of report can be tested by some form of what is known as the "*Aussage*" *Test*, and in connection with that test valuable light can also be thrown on the suggestibility of a subject. Various types of material have been used, but the principles underlying the testing of suggestibility are the same for all types of material. Hence the description of the test as usually given—that is, with a picture—will be sufficient for our purpose.

A picture is exposed for from twenty to thirty seconds, the subject being directed to observe closely, since he will be asked

[1] *La Suggestibilité.*

afterwards to tell all that he has seen. The test itself consists of two parts: (1) the report by the subject of what he has seen, given immediately or after the lapse of an interval of time; and (2) the cross-examination. We are particularly interested in the second part. The subject is required to reply to a series of prearranged questions, these questions being suggestive in different degrees. Any question is more or less suggestive, but the degree of suggestiveness can be varied by varying the form in which the question is put. Six types of question have been distinguished. These are:—

(*a*) The determinative question—the least suggestive form—which is a simple question introduced by the interrogative pronoun or adjective, as, for example, "What is hanging on the wall?"

(*b*) The completely disjunctive question, which compels the subject to choose between two alternatives, as, "Is there a cat in the picture?"

(*c*) The incompletely disjunctive question, which offers a choice between two alternatives, but does not exclude a third possibility, as, "Is the dog black or white?" which does not exclude the possibility of the subject replying with a third colour.

(*d*) The expectative question—a fairly strong suggestion—which assumes an answer, as, for example, "Was there not a picture on the wall?"

(*e*) The implicative question—the most suggestive—which is a question implying the presence of an object not present in the picture at all.

(*f*) The consecutive question, which is any question following up, and developing, a suggestion already given, or rising out of an answer already obtained.

Binet has employed a card of objects in place of a picture, but the procedure, as far as the testing of suggestibility is concerned, is identical. Possibly this kind of material affords somewhat more scope for suggestion, but that is doubtful. Other investigators have used an occurrence taking place in front of the subject, as, for example, the demonstration of some physical or chemical phenomenon. Obviously, then, we have a wide choice of material for the testing of suggestibility by this method. We cannot from the results, however, get a *measurement*, in any real sense, of an individual's suggestibility, owing to the complexity of the conditions entering in with the

question-and-answer procedure. As already indicated, if we wish measurements, we must be content with mass measurements, with the comparison of groups.

Summing up on the basis of the results obtained from experiments of the kind described, from experiments on subjects in hypnosis or in other hypnoidal states, and from observation in everyday life, we can specify the main conditions favourable to the operation of suggestion. These conditions are either objective or subjective, that is to say, they are either conditions dependent on factors external to the individual who receives the suggestion, or they are conditions involved in his state at the time. Take the objective conditions first. The general principle which will cover the operation of these conditions is, that whatever gives impressiveness to a suggested "idea" tends to favour its acceptance. The impressiveness may be either in the manner in which the idea is conveyed, or the source from which it comes. The applied psychology of advertising and salesmanship is deeply interested in this aspect of suggestion, and some experimental work has been done from this point of view. Psychologically, the impressiveness of the source is the more interesting. This is what we call "prestige." Two kinds of prestige are usually distinguished—*mass prestige*, or the prestige of numbers, and *personal prestige*. The first is the source of much of what we call the "crowd effect," and also of the influence of the constantly-repeated advertisement. Personal prestige may be either natural or adventitious, either permanent or only temporary. It may depend on personal qualities, physical, intellectual, or moral, on reputation, on wealth, on fine clothes, on profession.

The subjective conditions determine what we call the individual's suggestibility. Suggestibility may be a natural and congenital characteristic of a person, or it may be due to some condition, normal or abnormal, of the person at the time. Normal conditions, such as youth and inexperience, or lack of knowledge concerning a subject under discussion, it is easily seen, are conditions which will favour the acceptance of suggestion. So, also, will a favourable emotional state, an emotional state with which the suggestion chimes in, so to speak. Conditions, more or less abnormal, such as fatigue, the state under the influence of drugs, hysteria, hypnoidal states, such as the state between sleep and waking, and hypnosis, are similarly highly favourable to suggestion.

CHAPTER XI

FEELING AND EMOTION

WITHIN recent years there has been a notable transference of interest in psychology, both general and experimental, from cognition and the intellectual processes to feeling and the affective processes. Several causes have contributed to produce this result. In the first place, the biological interest in the behaviour of the living organism has extended to the affective processes because of their obviously close relationship to behaviour. In the second place, psychopathologist and psychiatrist have been led by the phenomena they encounter to attach more and more importance to the affective life, and this has reacted on normal psychology. In the third place, the practical interest in psychology as the science of human nature and character has received a new impetus in recent years, and this has always tended to lay stress on the affective processes. Previously, this part of psychology had been in a very backward state, at least as regards any exact scientific knowledge. It is not difficult to understand why this should have been so. Not only is the affective life of the human being very complex in itself, but feelings are, as such, very difficult to study introspectively. The complexity of the affective life is immediately realized when we consider the different varieties of feeling. Four distinct—or apparently distinct—varieties can be enumerated :—

1. The so-called *sense feelings*, that is, the agreeableness or disagreeableness attaching directly to our sense experience.
2. The kind of feeling we call *interest*, with the satisfaction or dissatisfaction it involves, according as the interest is gratified or meets with obstruction.
3. The affective elements involved in *emotions* and *moods*.
4. The feelings usually grouped together as *æsthetic feelings*.

The introspection difficulty has always been recognized. When we attempt to observe a feeling in attentive consciousness

we find that the feeling has vanished. This was all the more serious handicap for the older psychology, since introspection was the only available method of study. The application of experimental methods, however, has led to very considerable progress in this difficult field, and even introspection has been found capable of yielding results when systematically applied under experimental conditions.

It is far from easy to differentiate sharply between feelings and sensations. To such an extent is this the case that some psychologists have identified feeling with a rudimentary and undeveloped type of sensation. Several criteria, however, by which we may distinguish feeling and sensation, have been suggested, and, though all may not hold on all occasions, there is probably no case where all fail.

1. In the first place sensations represent an objective, feelings a subjective element in our conscious life. This means that sensation conveys to us a character of an object or situation, while feeling represents a state of ourselves. Organic sensations, including sensations of movement, present some difficulty as regards this criterion.

2. In the second place sensations have always a definite location, while feelings have no such location. This criterion has led to not a little controversy. It involves the view that different sensations may exist side by side in our experience at any moment, but feelings are coextensive with conscious life, and, therefore, mixed feelings cannot, as such, exist. Experimental evidence is very conflicting on this point.

3. In the third place, sensations range between maximal differences, feelings between opposites. It is characteristic of our affective life that it is bipolar, and no such bipolarity is found in our sense experience, though in some respects there are moderately close analogies.

4. In the fourth place, feeling is incapable of being reproduced as image. Again, there is some controversy regarding this criterion. We can, of course, remember an experience that, in the past, was tinged with feeling, but it seems true to say that the feeling we have is not a reproduced feeling, but a new feeling.

5. In the fifth place sensations and feelings behave differently in attentive consciousness. Sensations can become clear, feelings cannot. Like sensations feelings may vary in quality, in intensity, in duration, but they do not vary in anything

corresponding to sensible clearness, and this because they cannot be attended to in the way sensations can.

In spite of the fact that feelings and sensations differ from one another in all these ways, and of the fact that no one has any difficulty in concrete experience in distinguishing between a feeling of pleasure and a sensation, say, of blueness, there are, nevertheless, reasons for the psychological difficulties and controversies regarding feeling. On the one hand, every sensation possesses a feeling "tone," that is, is accompanied by a feeling of agreeableness or the reverse, and this has led some psychologists to class feeling with the attributes or aspects of sensation, thus denying it any status as a separate element of experience. On the other hand, feelings in their turn are always accompanied by diffuse organic changes, and this has led other psychologists to identify feelings with rudimentary and obscure organic sensations. Needless to say, the fact that two phenomena invariably occur together does not prove that they are identical.

The Simple Feelings.—There has been much discussion regarding the feeling elements, and at least one important attempt has been made to settle the question on an experimental basis. Wundt claimed that feeling may vary between opposites in any of three directions, the opposites being: strain and relief, excitement and depression, pleasure and displeasure. This is Wundt's *tri-dimensional theory* of feeling. He claimed, also, that the pulse and respiration of subjects showed distinctly the three dimensions of feeling. Thus he found that strain is accompanied by diminution of pulse in strength and in rate, and diminution of respiration in amplitude and in rate, while relief shows an increase in all four respects; excitement shows an increase in strength, but no change in rate of pulse, with increase in amplitude and in rate of respiration, while depression shows diminution in strength and no change in rate of pulse, with diminution in amplitude and in rate of respiration; pleasure is accompanied by increase in strength and diminution in rate of pulse, with diminution in amplitude and increase in rate of respiration, while displeasure gives diminution in strength and increase in rate of pulse, with increase in amplitude and diminution in rate of respiration. The relations are best seen in a table:—

	Pulse.		Respiration.	
	Strength.	Rate.	Amplitude.	Rate.
Strain .	−	−	−	−
Relief .	+	+	+	+
Excitement	+		+	+
Depression	−		−	−
Pleasure .	+	−	−	+
Displeasure	−	+	+	−

Unfortunately, other investigators have failed to confirm Wundt's results. On all grounds, experimental and introspective alike, we seem compelled to take the view that strain, relief, excitement, depression, in Wundt's scheme, are complex states of the organism rather than simple feeling states.

Experimental methods for the study of feeling fall into two main classes, according as attention is concentrated on the experience of the subject, or on the external behaviour and organic changes which accompany that experience. The two groups of methods are known as *methods of impression* and *methods of expression* respectively. For the present we shall confine discussion to the former, leaving the methods of expression to be described when we come to deal with the emotions in the next section of this chapter.

Methods of Impression.—In experimental work on the feelings, in which any one of the methods of impression is employed, the introspection of the subject is nearly always of first importance. Introspection of our feelings is, as we have seen, a somewhat difficult task. Hence, in order to get reliable results in this field, the subjects must be very carefully selected. Most of the standard work, indeed, has been done with subjects who were themselves expert psychologists. The same kind of thing has happened as regards most of the work on the thought processes, as we shall have occasion to note later. It is by no means certain that this is all gain in either case. In both cases the field is a highly-controversial one, and few psychologists will come to the work without having already adopted one or other of the theories. Psychologists themselves will be the first to acknowledge that too much weight must not be attached to introspective results in such circumstances, especially where the results support the previously accepted theories of the

subjects. Again and again it has happened that workers in different laboratories, working on the same problem, have got diametrically opposite results, the results in each case supporting the theories current in the laboratories in question. We so often, in experiments depending on introspection, get out of the experiment what we have ourselves put into it.

The simplest and crudest of the methods of impression may be designated the *Method of Choice.* In this case a number of objects are simultaneously presented to the subject, and he is asked to choose the object that gives rise to the most agreeable or the most disagreeable feeling. This method is experimentally of little value owing to the fact that it leaves the conditions so complex that analysis is all but impossible, either of the conditions determining choice or preference, or of the elementary phenomena of feeling. It is true that interesting points may be brought out by the introspection of the subject, but with the conditions so complex it is difficult for the introspection to be anything but unsystematic. The whole nature of the experiment is, so to speak, haphazard.

The best method for throwing light upon the elementary phenomena of feeling by means of the introspection of the subject is the *Method of Single Exposures* or the *Serial Method.* This method enables us to concentrate attention on the individual problems of our affective experience in a much more adequate way than any other of the methods of impression, and many valuable investigations have been based upon it. The stimuli are presented singly, and the presentation may be continued as long as the subject desires. They usually consist of simple sensory stimuli affecting any one of the sense organs. The subject is required to introspect as closely as possible, concentrating attention on the feeling aspect, and to describe his experience in full detail.

One of the most elaborate investigations by the Serial Method is that carried out by Wohlgemuth. He employed thirty-one different stimuli, tactile, olfactory, gustatory, auditory, visual, and painful. As illustrations of the type of stimulus the following might be cited: *tactile*—powder-puff, velvet, sandpaper; *olfactory*—vanilin, musk, scatol; *gustatory*—chocolate, quinine, acetic acid; *auditory*—tuning fork of 256, Galton whistle, scraping noise with piece of wood on a cigar box; *visual*—coloured papers; *painful*—prick on dorsal surface of the hand with a bristle, pinch with broad-pointed forceps.

The following is a typical introspection with the stimulus raspberry syrup: "First coolness, which was pleasant, then taste quality entered alongside, first indifferent, then became pleasant—the word 'sweet' occurred, and I gave myself up to enjoyment of sensation. Spectacular and passive attitude. With effort swallowed, wondering how sensation would change. Pleasure became more intense, sensation altering its character a little. There seemed to arise an element which I would describe as sickly, which was slightly unpleasant. This was simultaneous with pleasure, or oscillated quickly for some time."[1]

It is not necessary that single stimuli be given in the case of the Serial Method. The stimuli may be given in pairs, either simultaneously or successively, in which case each pair is regarded as a single exposure in the series. In Wohlgemuth's investigation, after the presentation of the stimuli singly, they were presented in pairs, first pairs of stimuli affecting the same sense and similar in quality, then pairs affecting the same sense but differing in quality, and finally, pairs affecting different senses. In some cases the stimuli were presented simultaneously, in other cases they had to be presented successively.

A third method, also of great value, is the *Method of Paired Comparison*. In this method the stimuli are presented in pairs, the subject being asked to say which of the two gives rise to the more agreeable or the more disagreeable experience; or it may be simply which he prefers. The method may be employed like the last for the study of the elementary phenomena of feeling. It is more usually employed, however, for the determination of the conditions underlying our likes and dislikes. Hence this method has come to be one of the chief experimental methods in studying æsthetic feelings, and might almost be said to be the basis of experimental æsthetics.

Since this method involves a comparison of two stimuli, it is evident that constant errors like the time and space errors must be taken into account. If the stimuli are presented successively, then it may make a difference which is presented first; if they are presented simultaneously, they cannot be presented at the same point in space, and the spatial arrangement may influence the affective experience produced. Hence, as in the

[1] *The British Journal of Psychology Monograph Supplements*, vi. ("Pleasure—Unpleasure"), p. 25.

case of the psycho-physical methods, steps must be taken to eliminate, and, if desirable, estimate the influence of these constant factors. The same procedure is adopted as with the psycho-physical methods. If the presentation is successive, then each comparison pair is presented in both time orders, if the presentation is simultaneous, in both spatial arrangements. Where a quantitative result is sought, the experiment must be conducted with the same care, precision, and rigid adherence to similar conditions of presentation, as when we are using one of the psycho-physical methods to determine a differential threshold. "Side comparisons" and "absolute impressions," or phenomena more or less analogous to these, will frequently be found to influence the results. For this reason presentation of the pairs in haphazard order will generally be found to give more reliable results than systematic presentation with one stimulus as standard in one series, another as standard in a second series, and so on.

We shall require to return to the consideration of some of these methods later, when we come to deal with æsthetic feelings. In the meantime the chief results obtained from the study by means of methods of impression of the simple feelings may be briefly summarized. With sense stimuli feeling has been found to depend on the quality, the intensity, and the duration of the stimulus. The more immediate dependence is, as one would expect, on the quality of the stimulus. The quality remaining constant, however, feeling varies with the intensity, and with the duration. As regards intensity, the general principle is that weak stimuli are indifferent (relatively), moderate stimuli pleasant, strong stimuli unpleasant. "Weak," "moderate," and "strong" are relative terms varying with the quality of the stimulus. In fact, we require almost to take the feeling tone produced as the criterion of the intensity in order to define the terms in this connection. The same general principle holds with respect to duration or protensity. In the case both of intensity and of duration the low degrees may be unpleasant, rather than indifferent, owing to the strain imposed on the attention of the subject, or to something akin to disappointment. Intensity and duration, as it were, combine their effects, though the phenomena sometimes become rather complex.

We have already alluded to the controversies with respect to mixed feelings, and with respect to feeling imagery. The attempts to study the problems experimentally have, so far,

failed to settle the questions at issue. With respect to mixed feelings, Wohlgemuth, as a result of the investigation already cited, comes to the definite conclusion that they exist, but there are great individual differences in the power of apprehending co-existing feelings. As regards the other problem, he also comes to a definite conclusion, but in the opposite sense. "There is nothing," he says, "on the affective side of consciousness to correspond with the memory image on the cognitive side."[1]

Another question regarding feeling, which has become specially prominent in recent times, is the question of the effect of feeling on remembering. Freudian psychologists maintain that there is a tendency to get rid of unpleasant feelings by forgetting. The view is, in fact, fundamental to certain parts of the Freudian theory. Wohlgemuth, on the basis of certain other experiments, came to the conclusion that there is no such tendency for unpleasant experiences to be forgotten.[2] It is very doubtful whether we can attach very much weight to the experiments in question. In any case the unpleasant experiences of which Freudians speak seem different in nature from those to which Wohlgemuth's experiment is relevant.

The Emotions

Very important experimental work has, in recent times, been done on the emotions. Much of this work is physiological rather than psychological in the first instance, but nearly all of it has a psychological bearing, and some brief notice must, therefore, be taken here, even of those investigations which do not fall directly within the sphere of experimental psychology.

There is no general agreement among psychologists as to how "emotion" should be defined. Külpe defines it as "a fusion of feeling and organic sensations," Höffding as "pleasure-pain in association with the idea of its cause." According to Sully it is "a mass of sensuous and representative material with a predominant affective tone," according to Ward "a complete psychosis involving cognition, pleasure-pain, and conation." The one thing that is clear—and these definitions may be cited in evidence—is that emotion is a complex, not a simple elementary, mental state. Under these circumstances description is more useful and appropriate than definition. An emotional state is characterized by :—

[1] *Op. cit.*, p. 220. [2] *Brit. Journ. of Psych.*, vol. xiii., p. 405.

1. A more or less pronounced affective tone—pleasure-un pleasure—experienced in connection with some object or situation.

2. A diffuse stimulation of organic processes, involving pulse, respiration, glandular secretions, which is usually spoken of as the *organic resonance* of the emotion, but which, according to the James-Lange theory, is identified with the emotion itself.

3. A narrowing and specializing of consciousness, both on the cognitive and on the conative side, the consequence of what we may call " emotional dissociation."

4. An impulsive force.

The basis of the experimental study of human emotion is, in the main, the second of these characteristics, that is, the organic resonance. This experimental study may be said to present two phases, the one, largely physiological, represented by work, like that of Pavlov, Bechterew, Cannon, and others, aiming at the analysis of the various organic processes, the other both physiological and psychological, utilizing the organic resonance for the study of the emotional state. We shall consider each of these phases in turn.

Bodily Effects of Emotion.—In his book *The Bodily Effects of Pain, Hunger, Fear, and Rage*, Cannon has given an admirable account of the recent work that has been done in this field, and the manner in which this kind of investigation has developed. The real development may be said to have begun with the work of Pavlov on the salivary reflex, which has been alluded to in a previous chapter. By means of Lashley's apparatus [1] for collecting the flow of saliva through Stenson's duct, work analogous to Pavlov's can be done with the human subject. Up to the present the amount of this kind of work actually done is inconsiderable, but some results are available, and experiments on animals yield results which are probably, in most cases, valid for the human being. The indications are that all emotional states affect the activity of the salivary glands. The emotions hitherto studied have all been emotions of characteristically *negative* polarity. In such cases the secretion of saliva is diminished or inhibited. There is a fair presumption that emotions of an opposite, or *positive*,[2] polarity will produce the opposite effect, but practically no experimental evidence.

[1] Watson, *Psychology from the Standpoint of a Behaviourist.*

[2] The two polarities of feeling have already been noted. They might be called *positive* and *negative* respectively. See Drever, *Instinct in Man* or *Psychology of Education.*

In addition to salivary secretion, Pavlov and his co-workers studied also gastric secretion. Similar results were obtained. Other workers have extended these investigations so as to include movements of the walls of the alimentary canal during the digestive process. X-ray photography must be employed to study these movements. Practically the whole process of digestion, therefore, has been studied in connection with emotional states. The general result so far obtained is that emotional disturbances of a negative polarity (that is, disagreeable) involve disturbance of the digestive function in all its aspects. The flow of saliva is diminished or altogether inhibited, and its chemical composition altered; the flow of gastric juices is similarly diminished or inhibited, and altered chemically; and the digestive movements tend to cease.

An interesting extension of this work is the study of the secretions of the endocrine, or ductless, glands, and particularly the adrenal glands, in consequence of emotional excitement. Much valuable work in this field has been done by Cannon. It had already been noted by various observers that the effect of emotional excitement on salivary and gastric secretion did not disappear immediately when the excitement subsided, or at least when its cause was removed, but frequently lasted for a considerable period of time. This fact suggested to Cannon the possibility that emotional excitement might involve an increased secretion of adrenin, and that this adrenin in the blood might have the effect of prolonging the inhibition of the activity of the digestive glands after the emotional excitement itself had disappeared. By testing the blood for adrenin after a period of emotional excitement, Cannon succeeded in showing that the quantity of adrenin in the blood is greatly increased as a result of strong emotion. Some of the effects produced by injecting adrenin into the blood had long been known. It was known that it caused the liver to pass sugar into the blood, that it altered the body distribution of blood, that it made the blood more coagulable, that it tended towards the elimination of muscular fatigue. Since emotional excitement increases the amount of adrenin in the blood, it must also, as a result, tend to produce these other bodily effects.

The influence of adrenal secretion in producing glycosuria (sugar in the urine) had been the subject of considerable controversy prior to the work of Cannon, but Cannon's investigations appear to establish the fact. In some experiments with

cats he removed the adrenal capsules and found that emotional excitement no longer produced glycosuria. Since emotional excitement is known to produce glycosuria in cats as in human beings under normal conditions, the presumption is strong that the glycosuria is produced as a secondary result of the activity of the adrenal glands in emotion.

The method by which Cannon demonstrated the influence of adrenin in increasing the coagulability of the blood was very ingenious, and is worth describing as more or less typical of this kind of experimental work on the emotions. The coagulation time was recorded graphically by means of a light lever, attached at one end to a vertical copper wire dipping in the blood, and almost counterpoised at the other end by a weight. The lever was allowed to rise every second at the lighter marking end, the copper wire passing into the blood to be studied. As soon, however, as the blood coagulated sufficiently to support 30 milligrams—the difference in weight between the two arms—the movement of the wire was checked, and the lever refused to rise. The record on the smoked surface thus recorded the coagulation time in seconds. Blood was drawn from the animal under normal conditions, and the time of coagulation recorded; and then blood was drawn after subcutaneous or intravenous injection of adrenin, and the time of coagulation again recorded. Cannon thinks that the more rapid coagulation following the injection of adrenin is not a direct effect on the blood, but is due probably to an initial effect on the liver. That the effect is produced by adrenin is certain. It is also certain, as a result of Cannon's experiments, that in a condition of emotional excitement the coagulability of the blood is increased.

The biological significance of the organic changes brought about by emotional excitement, and particularly of the activity of the adrenal glands, seems quite clear. The organic response is a biologically useful response. The increased sugar in the blood is available as a source of muscular energy. The vascular changes produced by adrenin are favourable to strenuous muscular exertion, as are the changes in respiration which take place. Even the more rapid coagulation of the blood possesses high biological utility under the conditions of primitive life, since it prevents loss of blood by wounds sustained in combat.

Cannon's investigations were confined to the bodily changes manifested in states of hunger, pain, fear, and rage. In all these cases we might describe the changes taking place as a

mobilization of all the bodily resources in face of a situation demanding every effort of which the organism is capable, in the interest of individual preservation. It is worth noting that Darwin, in his investigation of the laws of emotional expression, found the main law to be what he termed the "principle of serviceable associated habits," [1] that is, of biologically useful reactions. The characteristic movements, attitudes, and facial expressions, accompanying emotional excitement, may thus be brought under the same general rubric, as the more obscure changes in the involuntary muscles and glands. Phenomena like flushing or paling of the face are, of course, the results of the organic changes. But the complete picture of the emotion, which we see and recognize in the case of all the stronger and more violent emotions, is also produced by the contraction of various groups of voluntary muscles. There is, for example, the clenching or baring of the teeth in anger—preparatory, according to Darwin's view, for actual attack with the teeth.

In the same way the changes in pulse and respiration may, as we have seen, be also regarded as biologically useful reactions, so that practically all the bodily processes involved in emotional excitement, from changes in facial expression to changes in the secretion activity of the adrenal glands, can be brought under the same principle. The same can be said of the mental processes involved so long as the emotion does not reach too high a degree of intensity. There is a powerful impulse to action with dissociation affecting all lines of thought and action which are not relevant to the emotional state and its end.

Methods of Expression.—The study of feeling and emotion on the basis of the external behaviour and the bodily changes produced is the natural and necessary supplement of the *methods of impression* already described in the preceding section. Methods of expression are the only methods used by the behaviourist school, and, as far as the emotions are concerned, must always be the chief methods of the experimentalist, whether he is a behaviourist or not. The phenomena usually studied in this connection are: the changes in respiration, and in the rate and amplitude of the pulse, involuntary movements, voluntary muscular contraction, blood pressure, the psycho-galvanic response, and free association, the method employed in any case being appropriate to the particular phenomena studied.

[1] *Expression of the Emotions*, p. 28.

Respiration and pulse are studied in practically the same way, that is, by graphic record on a smoked drum. In order to obtain such a record two tambours, or small rubber-faced chambers, are employed—a receiving tambour and a recording tambour—connected by rubber tubing. For recording respiration the receiving tambour, or *pneumograph*, may take a variety of forms. The essential point is that inspiration and expiration should change the air pressure within a chamber closed by a rubber membrane, and that those changes should be transmitted to another chamber with a rubber membrane, upon which a light lever rests. By the changes of pressure the lever is moved up and down with the breathing of the subject, and it marks the curve of breathing on the surface of a smoked drum. For recording the pulse a capsule, attached to, or resting against, the rubber membrane, is placed on the wrist, so as to receive the pulse beat, and the other arrangements are similar to those for recording respiration. In place of a receiving tambour an inflated rubber band may be used, this being fastened round the wrist. Either receiving tambour or rubber band is called a *sphygmograph*. Blood pressure is measured by means of the *sphygmomanometer*. An armlet, as just described, is placed round the wrist. This is inflated, and the air pressure increased, till the pulse in the wrist is just abolished. By any suitable manometer a continuous record can be obtained of the increasing pressure in the armlet, which is connected to the manometer in place of a recording tambour, and that pressure at which the pulse just disappears is the blood pressure.

Involuntary movement is studied by means of the *automatograph*, which is merely a planchette with a laboratory name. It is simply a light board, on which the arm rests comfortably, suspended from the four corners, so as to swing freely, and provided with a stylus for marking on the smoked surface placed underneath. The subject rests his right arm on the board, and tries to take up as comfortable and as natural a position as possible. The stylus is then brought in contact with the smoked surface, and the "normal tremor" of the subject recorded. It is very important that the subject should be as nearly as possible affectively indifferent when this is being taken. The comparison of this with the record under affective conditions gives us our results. Voluntary muscular contraction may be studied either by means of the *dynamometer* or *dynamograph*, or by means of the *ergograph*. The former is, perhaps, preferable.

The dynamometer is an apparatus for measuring *strength* of muscular contraction—usually strength of grip—the dynamograph merely a modification so as to obtain a graphic record. We begin by taking the subject's normal curves for a given period of time. This serves as a basis of comparison for the curves obtained under affective conditions.

The psycho-galvanic response, or "reflex," has recently come into considerable prominence in connection with the experimental investigation of emotion. Whether it is what some

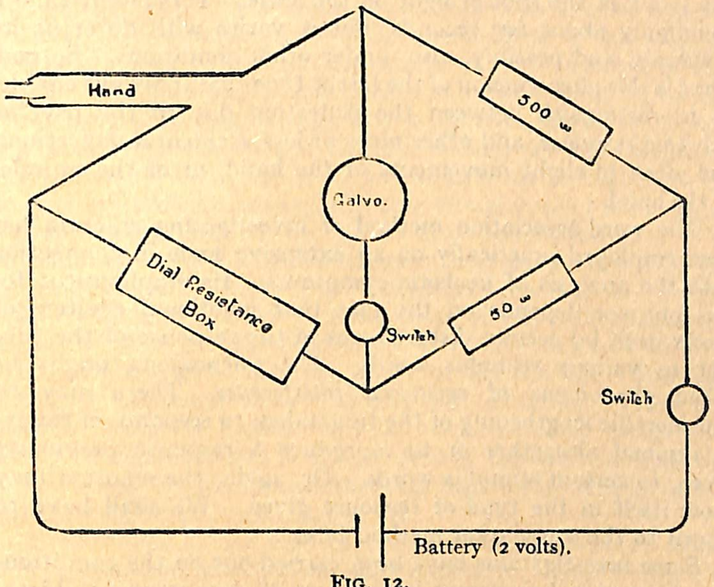


FIG. 12.

investigators claim for it[1] or not, it is certainly a very interesting phenomenon. It depends upon the fact that the electrical resistance of the skin is diminished as a result of affective disturbance. The simplest arrangement by which it may be demonstrated is for the subject to have his left arm placed in one arm of a Wheatstone bridge and balanced against a variable resistance, the constant arms being arranged with resistances in the ratio 10 to 1. (See Fig. 12.) A mirror galvanometer is used, and the deflection of the spot of light on the scale indicates

[1] See, for a somewhat extreme view, *The Measurement of Emotion*, by W. Whately Smith.

any change of resistance in the hand, the amount of the change being approximately shown by the amount of the deflection. Practically any stimulus given to the subject will cause a deflection, and always in a direction indicating lowering of the resistance of the hand, but the most striking results are obtained when the subject is asked to reply to a stimulus word with the word that first comes to mind, that is, by combining the free association experiment with the psycho-galvanic experiment. There is always a latent time between the giving of the stimulus and the swing of the spot of light on the scale. This latent time is commonly about *two* seconds, but it varies with different individuals, and possibly, also, under other conditions. So constant is this phenomenon of the latent time that it always enables us to distinguish between the deflection due to the psycho-galvanic response, and other more or less accidental deflections, due often to slight movements of the hand, or of the muscles of the hand.

The word-association method of investigating emotion has been employed practically on an extensive scale in connection with the analysis of neurotic symptoms. Its employment for this purpose depends on the fact that emotional excitement shows itself by certain disturbances in the response of the subject to various stimulus words. The phenomena might be called phenomena of *emotional interference*. There may be considerable lengthening of the time taken to respond, or failure to respond altogether or to reproduce a response previously given, to certain stimulus words. Or, again, the emotion may show itself in the type of response given. We shall have to return to the association method later.

Some investigations have been carried out on the conditioning of emotional responses in the case of very young children, the results of which may be variously interpreted according to the theory of emotion held, but are at least of considerable interest on any theory. Thus Watson and Rayner [1] found that a child of eight months responded with the fear reaction to the loud noise made by striking a suspended steel bar with a hammer. At eleven months the conditioning experiments were begun. The child initially showed no fear of a white rat, but as he touched the rat the bar was struck. The fear response was at once given. This double stimulus was repeated once the same day and five times a week later, when it was found that the fear response was

[1] *Journal of Experimental Psychology*, vol. iii., p. 1.

given consistently to the rat alone. Five days later it was found that the response was still elicited by the rat alone, and also by a rabbit, a dog, a fur coat. The response was still present a month later.

The Æsthetic Feelings

Experimental Æsthetics.—Æsthetic feelings in a strict sense are feelings evoked by the contemplation of a work of art, which are due neither to the pure sense pleasure derived from the stimuli, nor to the feelings and emotions evoked sympathetically by what is artistically represented, or by way of association based on past experience of the object contemplated. Not that æsthetic feelings are in their essential nature a new type of feeling, though this is, perhaps, arguable, especially with reference to the feelings evoked by the beautiful. The preferable view, however, would seem to be that æsthetic feelings are such because of the way in which they are evoked. We shall have more to say about that point presently. The experimental study of æsthetic feelings is not confined to the æsthetic in this strict sense. Æsthetic feelings are rather understood in the wider popular sense of any feelings evoked by contemplation of the products of any of the fine arts, without any limitation as to the real source of the feelings. The field of study has been called *experimental æsthetics*. From the objective point of view it may be described as an analysis of art by the employment of the method of experiment, from the subjective as the analysis of æsthetic experience, that is, of our appreciation of the beautiful in art.

Experiment in the field of the æsthetic, as in other fields, must commence with the simplest elements. Accordingly, the main work done up to the present has been concerned with the study of preference for simple colours, simple combinations of colour, simple forms, musical intervals, rhythms, together with a study of the reasons for such preference. Some experimental work has been done with more complex material, as pictures and musical compositions, but the more complex material has tended to obscure rather than illumine the main lines of æsthetic experience. As a matter of fact, the chief types of æsthetic enjoyment, and the main principles, so far disclosed, upon which æsthetic enjoyment depends, may be revealed in experiments with simple colours or simple forms.

Let us begin by considering the pleasure derived from colour,

and the conditions upon which colour preference depends. An important investigation by E. Bullough [1] into the reasons why colours are liked or disliked was carried out by the serial method, which has already been described in the first section of the present chapter. He employed in all seventy different hues, shades, and tints. The subject looked through a circular aperture at the colour, which was in bright and constant light, and had to say whether he liked or disliked it, and his reason for liking or disliking. It was found that the subjects—thirty-five in all—fell into four groups according to the aspect of the colour determining their like or dislike. We may provisionally speak of four *æsthetic types*: (1) The first type liked or disliked a colour for its objective qualities as a colour, i.e. because it was saturated, or pure, or bright, or thin, or dull. This might be called the *objective* type. (2) The second type liked or disliked a colour because of its physiological effect on the observer, i.e. because it was stimulating, or soothing, or depressing. This physiological effect of colours had already been demonstrated by several investigators, notably by Féré, who showed that the strength of grip was affected by colour stimuli. This type might be called the *physiological* type. (3) The third group liked or disliked a colour because of its association with some agreeable or disagreeable object or event in their experience. We may call this the *associative* type. (4) The like or dislike of the fourth group was determined by what Bullough calls the "character" aspect of a colour. Colours were regarded almost as if they were persons, and characters attributed to them, as jovial, sympathetic, stubborn, aggressive. This type we may call the *empathy* type.

It is a little misleading to speak of types, at least if this suggests that subjects fall into four mutually exclusive classes. As a matter of fact subjects frequently gave at one time reasons for their like or dislike which would mark them off as belonging to one type, while at another time they gave reasons characteristic of quite a different type. The four types of appeal, however, which colour may make, or the four aspects of colour which may evoke feeling, are quite clear. These four types of appeal may be regarded as representing stages of æsthetic development, of which the physiological type represents the lowest, the empathy type the highest. The latter alone is the

[1] *British Journal of Psychology*, vol. ii.

æsthetic appeal in the strictest sense of the term. Only so far as we become absorbed in an object in such manner as to identify ourselves with it, to *be* it for the time, do we have the truly æsthetic experience.

Another method that may be employed in the study of colour preference is the method of paired comparison, which has also been already described. This is the method that must be employed if we desire reliable quantitative results. The colours to be compared are presented in pairs, every colour twice with every other, the places of the colours being interchanged the second time in order to eliminate any space error. It is important that all the conditions of presentation should be kept the same throughout. The subject expresses preference by pointing to the colour preferred, and tries to give the reasons for the preference. In order to arrange the colours in their order of preference at the end of the experiment, all that is necessary is to add up the number of preferences given to each. Where there is no preference between two colours, each of the colours will, of course, score a half. It goes without saying that the results are valid only for the precise colours and shades used, and this fact must be kept in mind in view of the discrepancies between the results obtained by different investigators. In an investigation in the Edinburgh George Combe Laboratory, with 144 subjects (90 women and 54 men), the colours used were red, green, yellow, blue, violet, and purple (all saturated colours of the Bradley series). These colours were arranged in the order: blue, violet, green, yellow, red, purple, by the women, and in the order: blue, violet, purple, red, yellow, green, by the men. The actual preferences given to each colour, out of a possible 10, were :—

Women.		Men.	
Blue	6·5	Blue	6·8
Violet	6	Violet	5·1
Green	5·7	Purple	5
Yellow	4·7	Red	4·7
Red	3·8	Yellow	4·4
Purple	3·6	Green	3·9

Apart from blue and violet, which tend to be placed first and second respectively by both men and women, it will be observed that there is a somewhat remarkable reversal of order

as regards the other colours. It will also be noted that blue gets a clearer preference over violet from the men than from the women. With the former violet is only slightly superior to purple, while it is much more strongly preferred to the third colour (green) in the case of the latter. This experiment has been repeated with the graduating class in psychology for several years, and, while the general results have remained fairly constant, it has been found that the preference, especially of the women, is considerably influenced by the fact that a particular colour happens to be popular or fashionable at the time. Another interesting point that has emerged is that every colour has its votaries, and there is considerable constancy as regards the arrangement of the other colours among those who prefer any one colour.

A number of investigators, using different methods, have studied the colour preferences of children of various ages. Valentine, using a paired comparison method adapted to the situation, based on the time the child looked at different colours, found for a child of three and a half months the following order of preference: yellow, white, pink, red, brown, black, blue, green, violet.[1] Generally speaking, investigators have found that yellows and reds are the preferred colours with very young children. Winch, using much cruder methods, investigated the colour preferences of children at different stages of their school career, and found that blue very soon takes front rank, but red retains second place with both boys and girls, while green is very low with the younger children, but gradually moves up the list. Among adults green tends to take a place alongside of blue. The method employed, however, was open to serious criticism. Winch asked his subjects, children and adults alike, to write down the colours: white, black, red, green, yellow, blue, in the order in which they liked them.[2] Most experimenters will agree that results obtained under these conditions may mean very little.

Combinations of colours may be experimentally investigated in the same way as individual colours. Bullough, in another important series of experiments with two colours,[3] studied the effect of the apparent *heaviness* of colours in determining preference for a certain spatial arrangement of the colours. He employed the geometrical forms, triangle, circle,

[1] *British Journal of Psychology*, vol. vi. [2] *Ibid.*, vol. iii.
[3] *Ibid.*, vol. ii.

and square. The upper and lower halves of the figures were occupied by the two colours respectively. In most cases preference was given by the subjects to that figure in which the *heavy* colour was below. In general, the *heavy* colour was the darker or more saturated colour, but sometimes this objective *weight* was more than counterbalanced by a subjective *weight*, as, for example, preference for a certain colour. It cannot be doubted that this *weight principle* is of very considerable importance in determining æsthetic experience, with complex as with simple objects, and we shall have other examples presently.

In pictorial art we are concerned with beauty of form as well as beauty of colour. The same methods have been applied to the study of the conditions determining preference of elementary forms, that is, simple straight lines and curves. In very many cases subjects, while expressing a distinct liking or the reverse for a line or curve, were unable to give any definite reason for this feeling. When, however, reasons were given they were of the same kind as with colours. In particular, associations were found to play a very important part in determining feeling. So, also, the suggestion of movement in the lines frequently determined feeling. This last we might regard as analogous to the empathy aspect of colour. At this point experimental work on the æsthetic feelings touches closely on the experimental work on the geometrical optical illusions, which we have already discussed.

Somewhat more complex test material, consisting of figures formed of two or more lines, has also been employed, and in connection with such material a second important æsthetic principle has emerged. This may be called the *principle of symmetry* or *balance*, and may be regarded as analogous—or, perhaps, complementary rather—in the sphere of form to the *weight principle* in the sphere of colour. In dividing a line into two parts, in placing two lines of the same or different lengths inside a rectangle, in placing two lines of unequal lengths, one on either side of a third line, subjects are found to express marked preference for a certain arrangement which seems to them symmetrical. In dividing a line, for example, a symmetrical effect could be obtained, and was obtained most frequently, when the line was unequally divided. It has been maintained that this symmetrical division always corresponds to what is known as the "golden section," that is, division so that the

whole line bears the same ratio to the larger part as the larger part to the smaller. Careful investigation, however, has failed to substantiate this view. It has been found that there is considerable diversity in the divisions approved by different subjects. In any case the shorter part, somehow, gets more *weight* than the longer, sometimes even to the extent of producing an illusion that it is thicker, and the increased *weight* is the basis of the symmetry, balance, or equilibrium. So, again, if two lines, one of which is double the length of the other, are to be placed vertically inside a rectangle, that arrangement is preferred in which the shorter line is double the distance of the longer from the middle point of the rectangle. In this case, it is interesting to note, the respective positions of the lines are those of mechanical equilibrium.

This *principle of symmetry* has been found to have a wide application in the arrangement of pictures on a wall, or of furniture in a room. It is also exemplified in all great pictures. In all these cases the balance or symmetry most frequently depends on the operation in various ways of the *weight principle*, and sometimes the conditions are very complex. In placing a small picture and a large picture on the same wall, we do not necessarily place them in a position corresponding to that of mechanical equilibrium with reference to the middle point of the wall. A crude taste might, indeed, so arrange them. Most frequently, however, subjective factors, rather than objective factors like size, determine the relative *weights* of the pictures, and they are arranged accordingly. In the same way the balance of a great picture is rarely, if ever, a mechanical balance, or even approximately so. Subjective interest determines *weights* in the different parts, and the picture is a symmetrical whole by the balancing of these.

The dependence of æsthetic appreciation upon the *principle of symmetry* would appear to indicate that æsthetic experience depends on intellectual or cognitive, as well as affective, factors. This is doubtless true. At the same time it is not difficult to see how empathetically evoked feeling would be affected by symmetry. Technique also enters as a factor determining æsthetic enjoyment, especially that of the expert, and again, this would appear to introduce a cognitive factor, but one which will indirectly affect empathetically evoked feeling.

Experimental work has also been done in the auditory field with musical sounds and rhythm. The same methods have

been employed, so far as they were applicable, and very similar results have been obtained. When Valentine[1] studied the æsthetic appreciation of musical intervals he found almost exactly the same aspects of the auditory situation determining likes and dislikes, as Bullough found with colours. Sometimes the objective aspect, sometimes the physiological or subjective, sometimes association, sometimes empathy, determined the affective response. The order of preference for musical intervals was also studied by Valentine. He found the major third to be the most agreeable to his subjects, and the minor second the most disagreeable. He also found in a prolonged experiment that the affective value of intervals, which were disagreeable to begin with, underwent a remarkable change as the experiment proceeded, so that ultimately they became agreeable. Attempts to use complex material in this field have, so far, led to little definite result. For example, an attempt to determine the extent to which music is definitely expressive of certain emotions gave very inconsistent results.

[1] *British Journal of Psychology*, vol. vi.

CHAPTER XII

IMAGERY AND ASSOCIATION

AN image may be briefly defined as a revived percept without stimulation of the sense organs from an external source. Of course, this definition is not accurate, since an image, *ex hypothesi*, is not a percept. Essentially, however, it is of the same order of experience as a percept. Thorndike defines images as "feelings of things, qualities, and conditions of all sorts as not present." [1] It is very questionable whether the qualification "as not present" ought to have been appended instead of the more usual "not affecting the sense organs at the moment." The essential point to keep in mind is that the content of a sense experience—a sight, sound, touch, and so on—may be revived later, when the sense stimuli are absent; in such case it is revived as "image." Or, if we speak in terms of situations rather than sensations or sense percepts, the *representation* of a situation without actual restimulation of the sense organs from without is in the form of an image, whereas its *presentation*, based on stimulation of the sense organs is in the form of a percept. Hence the level of mental life at which mental process is carried on by means of images is spoken of as the level of *ideal representation*.

An excellent way of realizing the nature of the image, and the ways in which it differs from the percept, and also from what has been erroneously termed an "after-image," is to look for a little—say a quarter of a minute—at a circular piece of paper, one-half of which is coloured blue, and the other half yellow, placed on a large sheet of grey paper. At the expiry of the quarter of a minute let the piece of paper be withdrawn, but continue to look at the grey surface where it lay. There is, first of all, a percept of the blue and yellow paper. This is followed on the withdrawal of the paper by a succession of so-called after-images in the complementary colours, these

[1] *Elements of Psychology*, p. 43.

colours gradually becoming less and less saturated as the vividness of the after-images diminishes. Finally, when there is no longer any trace of after-image, one can still *recall* with considerable vividness the coloured paper as it originally lay on the grey background. This, also, will gradually diminish in vividness and fade away ultimately, but its fading away will be of a different kind from the fading away of the after-image, and even after it has faded away it can always be recalled at will with a certain degree of vividness, though not, perhaps, the same vividness as at first. Here, then, we have a series of experiences, a sense percept based directly on sensation, a succession of after-images, which are really after-sensations, the *primary memory image*, which is a real image, and a succession of memory images, as long as we care to go on reviving the experience. We can only have the percept while the coloured paper lies before us and stimulates the organ of vision; we can only have the series of after-images while the excitation in the organ of vision passes through the changes following upon the withdrawal of the stimulus; but the real image we can have at will, independently of the presence of the coloured paper, after the first time, or of the excitation processes in the retina.[1]

The image has the same aspects or attributes as the original sense experience, and corresponds, in the main, to the original sense experience as regards these aspects. For example, an imaged tone has pitch, and approximately the same pitch as the originally experienced tone of which it is the image. So, too, it has intensity corresponding to the intensity of the original tone, and it has approximately the character of the original tone in all its aspects. In addition it has, as an image, the characteristic of vividness, and this vividness is not to be confused, nor, indeed, is it commensurate with sensational intensity.

For evidence of the presence or absence of an image in the mental life of the human being, we naturally look to introspection. In order to determine whether an image is present in the mental life of one of the lower animals we must seek evidence of a different kind. Such evidence is obtained from

[1] With many children and some few adults a type of image which has been called the "eidetic" image may be obtained. This has many of the characters of actual perception and may be considered as a transitional type of experience between percept and memory image. See Article by Allport in *British Journal of Psychology*, vol. xv, Oct. 1924, and Jaensch's *Eidetic Imagery* (Intern. Library of Psychol.).

what is known as the *deferred reaction experiment.* This depends upon the function which the image performs. The image enables an individual to utilize a past experience in reacting to a present situation. If an animal has learned that the right exit from a box is that in which a light is shown, and that animal is capable of having a memory image, it ought still to find the right exit when the light is shown and put out before it is released. This is the basis of the "deferred reaction experiment." As far as the results of this experiment go, there is no clear evidence of a memory image except at a point high up the animal scale. Study of the behaviour of animals under less artificial conditions would seem to indicate, however, that the image function is present much lower down the animal scale.

Types of Imagery.—When we speak of an image in ordinary speech we nearly always mean a visual image. It must be remembered, however, that we can have images belonging to any sense department. In the mental life of the vast majority of normal individuals, visual, auditory, and motor imagery are the prevailing types, and of these probably visual images usually predominate. The predominance in the mental life of any individual of imagery belonging to a certain sense department is marked by speaking of the individual as belonging to a certain *ideational type.* Thus, we speak of an individual as a *visile*, an *audile*, a *motile*, and so on, according as the imagery is predominantly visual, auditory, motor. It was formerly held that this difference in sense type of imagery was a fundamental and probably congenital difference between people. This view has been very much modified within recent years. Though hereditary differences may underlie differences of type in at least some cases, it is certain that the predominance of a type may be due to accidents of environment or education, and that most of us belong to mixed types. It has also been found in experimental work on imagery that the type of imagery of a subject may change during the course of the experiment.

Several methods are available for determining an individual's predominant type of imagery. Perhaps, when everything is taken into consideration, the best method is still Galton's *questionnaire method.* It certainly yields more comprehensive results than any other single method, and in the mass the results may be taken as fairly reliable, though in any individual case the reliability varies with the introspective ability of the individual Galton employed the *questionnaire* method widely,

and has laid down the principles in accordance with which the questions ought to be formulated. These are: (1) the questions must be easily understood; (2) they must be easily answered; (3) they must cover the ground which the problem to be solved covers. Galton asked his subjects to call up in imagination certain objects or experiences, and then to answer specific questions regarding the imagery. For example, the subject was asked to call up the "beat of rain against the window-panes," and to record whether the image was "very faint," "faint," "fair," "good," or "vivid and comparable to actual sensation." Galton's enquiry was intended to throw light particularly on visual imagery, and accordingly the *questionnaire* included a long series of questions addressed to this end. He asked his subjects to call up an image of their breakfast-table, as they sat down to it "this morning," and then to answer such questions as: Are the colours of the china, of the toast, mustard, etc., quite distinct and natural? Then he asked them to call up the image of some panoramic view, and to say whether they could see mentally "a wider range of it than could be taken in by a single glance of the eyes." There were also general questions such as: Can you retain a mental picture steadily before the eyes? Where do mental pictures appear to be situated? Can you easily form mental pictures from descriptions of scenery? [1]

A second method is the *word-list method*. This does not demand any training in introspection, at least in the first of the two forms of the method that have been employed. In this first form, which we owe to Kraepelin, the method consists in asking the subject to write out a list of objects that are characterized by their colour, of those characterized by their sound, and so on, five minutes being allowed for the writing of each list. In the second form of the method the experimenter prepares two lists of words. The first is presented to the subject visually one at a time, and the subject records the kind of imagery aroused—both word imagery and object imagery. The second list is read to the subject one word at a time, and the subject records his imagery as before. Obviously, this form of the method permits only of the two modes of presentation.

A third method is the *learning method*, or *letter-square method*, as Titchener calls it.[2] This method may be applied in

[1] *Enquiries into Human Faculty* (Everyman Edition), p. 265 f.
[2] *Experimental Psychology*, vol. i., pt. ii.

various ways, but a typical series of experiments might be carried out as follows: A number of cards are prepared, marked with twelve squares, in each of which a letter is placed, the subject being provided with similar cards with the squares blank. The letters are either read over by the subject for ten seconds, or are read over to him at a constant rate by the experimenter. After the lapse of a given interval of time—say twenty seconds—the subject makes an attempt to reproduce by filling in the letters on one of his blank cards. The interval is filled by counting aloud from 1 to 20 on the part of the subject. Various complicating conditions may be imposed on the learning. In some cases the subject may be required to learn silently, in others to read the letters aloud, in others to keep repeating a constant sound like "la" while he reads them. The nature of his imagery is shown by the success of his reproductions under the different conditions, and by the kinds of errors he makes. Not only is the predominant type of imagery indicated by the relative facility in learning with purely visual or visual *plus* auditory presentation, respectively, but the visual type will also be indicated by the relatively small influence exerted by the repetition of the constant sound during learning, the auditory type by the relatively great influence, and so on. The nature of the errors made in reproduction after practically any learning experiment will also throw light upon the predominant imagery of the learner. Thus, in reproducing letters, the visual learner substitutes letters of similar appearance, the auditory, letters of similar sound.

Association

In the processes we call "remembering" and "imagining" the mental content consists of trains of imagery in the same way as the mental content at the perceptual level consists of trains of percepts. The order and succession of the percepts constituting perceptual trains is determined for us by the order and succession of the objects affecting our sense organs, and therefore on the one hand by the independent world order to which we must adjust ourselves, and on the other hand by our own activity relative to that independent world order. Hence our trains of percepts may be said to have a permanent basis in the external world order. In accordance with our definition of an image, it is independent of the present effect on our sense organs of external objects. Consequently, trains of images cannot be determined by the external

world order in the same way as trains of percepts are. Images are relatively free as regards the here and now of the world order. Nevertheless, they, also, are determined directly by conditions peculiar to the ideational and conceptual levels of mental process. Of these conditions we must, at present, consider those usually grouped under the head of *association*.

The important part which association plays in the mental life is indicated by the fact that the English School of Psychology, as it is called, explained practically all our mental processes, and more particularly the higher and more complex processes, in terms of association. John Stuart Mill, in fact, finds in the "principle of association" a parallel in the mental life to the principle of gravitation in the physical world.

It is possible to regard association as dependent primarily on physiological conditions, as being, indeed, as James says, a particular case of the physiological or neural law of habit. But there are several phenomena connected with association, which are unexplained by all we know of physiological process. This point ought to be kept clearly in mind, all the more because such attempts at physiological explanation and interpretation are very frequent in psychological works. It will generally be found that the physiological facts appealed to are not facts independently known by the physiologist, but merely physiological translations of the psychological facts to be explained.

One illustration may be given to show that the physiological law of habit is, in itself, insufficient to account for the facts of association. According to James' view, in experiencing A followed by B, the nervous current passes from a cell or cells in which A is registered to a cell or cells in which B is registered. In consequence there is, as it were, a track connecting the two systems of cells, which facilitates the passage of nervous energy in the future, so that when the system of cells representing A is again active, there is a tendency for those representing B to become active immediately afterwards. Now it is a well-known fact that experiences are, or tend to be, revived in the same order as they were originally experienced. Association has, as it were, direction. A tends to revive B much more readily than B tends to revive A. This is, in itself, a difficulty for the physiological theory, but it is not an insuperable one. The difficulty becomes much more serious when we consider more complex cases. A may be bound by association to a B which, in the original experience, was separated from it by a considerable interval of time, and by links far more stable

and enduring than those which bind it to experiences immediately contiguous to it in point of time. Moreover, according to the context, A may evoke by association C, or D, or X, in place of B. And B is just as likely to evoke A in one context as A is to evoke B in another.

The Laws of Association.—Considerable variety is displayed in the treatment of the "laws of association" in psychological text-books, and considerable differences with regard to the terms in which they are stated. At the same time there is substantial agreement as to the facts. The distinction is usually drawn between the laws known as *primary*, and those termed *secondary*, laws of association. The latter are not really laws of association in any exclusive or peculiar sense, but have a wider reference, and are really general statements of the conditions which determine the tendency to revival of any mental process whatever. The former are more strictly laws of revival so far as that is dependent on association.

We may begin with the secondary laws. The phenomena which are covered by these laws are familiar in ordinary life, and can be easily studied under experimental conditions. The laws are four: the law of *primacy*, of *recency*, of *frequency*, and of *vividness*. The statement of these laws is very simple. In each case the qualification "other things being equal" must be understood. The law of "primacy" would then be stated: "First impressions and associations tend to persist longest, and to be most easily revived." The law of "recency" would run: "Recent impressions and associations recur most readily to mind." The law of "frequency" would be expressible in some such form as: "The more frequently an impression is made or an association formed, the more permanent is the retention and the easier the reproduction." Finally, the law of "vividness" would take the form: "The more vivid an impression or association the more enduring is its influence, and the more easily is it recalled."

All these laws, as we have indicated, can be verified by quite simple experiments. Stimulus sheets may be prepared, on which colours and numbers are presented in series, either in pairs—a colour and a number together—or singly—first a colour, then a number, then another colour, then another number. The presentation must be at a constant rate. Test sheets are also prepared so that the colours can be exposed without the numbers, the subject being required to give the

number suggested by each colour presented. Stimulus and test sheets are prepared in such a way as to emphasize now frequency, now primacy, now recency, now vividness. In estimating the influence of each factor in the final results, the operation of previous associations of colours with numbers, and of chance, must be discounted.[1]

The primary laws of association have been frequently given as the law of *contiguity*—experiences which are contiguous to one another in time tend to be associated together, so that the first tends to recall the second—and the law of *similarity*—similar experiences tend to be associated together, so that the one recalls the other. The first law is valid and fundamental. The second law is of doubtful validity when stated in this form, and in any case is merely a particular case of the operation of the first. We ought, however, to speak rather of the law of *systemic relations*, and state the law in some such form as: "Our experiences, on the basis of continuity of interest, and the unity and continuity of the attention process, determined by interest, tend to form wholes or systems. The result is that associative bonds are established between the wholes and their constituent elements, between the constituent elements and one another, and between the constituent elements and the whole." This is the main law operative in the case of our higher thought processes and our organized knowledge. It would also cover frequently occurring phenomena of our mental life, especially in reverie and dreams, where the basis of the association determining the succession of thoughts is a common affective response.

The operation of the primary laws is illustrated by practically any form of association experiment, and these laws may also serve as a basis, as we shall see presently, for the classification of associations. In the meantime it is necessary for us to consider the different types of association experiment, all of which are important for the use that has been made of them, both in the laboratory and in clinical and therapeutic work. Association experiments have already been briefly described.[2] They are usually conducted with stimulus words, which are either presented visually to the subject by means of some suitable exposure apparatus, or spoken by the experimenter.

[1] See Titchener, *Experimental Psychology*, vol. i., pt. i., p. 200

[2] See chap. viii.

The subject responds with another word expressing some idea associated with that expressed by the stimulus word. If the subject is left free to respond with the first word that comes to mind we have the type of experiment known as the *free* association experiment. If he is required to respond with a word standing in a definite relation to the stimulus word, we have the *constrained* association experiment. The constraint may be complete, as when there is only one correct response, or it may be partial, where the subject is left with some degree of choice. The free association experiment may be modified in such a way that only the first stimulus word is given, each response thereafter functioning as a stimulus word for the next response. That is to say, the subject is merely started on a train of thought by the stimulus word, and each response word indicates the direction the train of thought is taking. This is known as the *continuous* method, and it is characteristically the method adopted in Freud's psycho-analysis.

Free Association.—While constrained association experiments are of great interest theoretically, and we shall require to revert to their consideration when we come to discuss the thought processes, it remains true that from the general point of view the free association experiment is by far the most important, even apart from its employment by Freud in his psycho-analysis. The employment of free association on a wide scale for diagnostic purposes appears to have originated with Jung. Before describing Jung's Association Method, however, some notice must be taken of another method of diagnosis, not quite so well known, but deserving of being much more widely known than it is. That is the method used by Kent and Rosanoff,[1] to determine how far an individual's mental content and direction of thought are usual or unusual, normal or abnormal. These investigators prepared a list of a hundred common words. These words were given as stimulus words to a thousand normal subjects, and all the responses recorded. The responses were tabulated with the number of subjects giving each particular response. In this way a *frequency table* was obtained showing the frequency with which any response had been given, the frequency being taken as indicating the usualness or unusualness of any response. A frequency table having once been drawn up, we are able to give the test series of words to any individual,

[1] *American Journal of Insanity*, vol. lxvii.

record his responses, and determine the average frequency of these responses, using the frequency table. The average frequency may be taken as a measure of that individual's normality in mental content and direction of thought. The frequency of any response not given in the frequency table is recorded as zero, the response being designated an *individual* response. The number of individual responses is an indication of the " eccentricity " of any particular subject. In this method no use is made of the association time.

Jung's Association Method employs also a series of a hundred stimulus words, very similar superficially to the Kent-Rosanoff series. They are selected, however, in such a way as to call up by association commonly occurring emotional states and emotional complexes. In giving the words the experimenter, in addition to recording the response, times the response. After the series has been gone through, the experimenter goes through it again, asking the subject to reproduce the response word previously given. If a response is not given in thirty seconds the experimenter goes on to the next word, and records a failure to respond, or *fault*.

In drawing conclusions from this experiment the experimenter mainly takes account of (1) the time of response; (2) the nature of the response given; (3) failure to respond or to reproduce. When the time taken to respond in any particular case is very much above the average time of response, it is assumed that the stimulus word, or an immediately preceding stimulus word, has touched an emotional complex, and that the lengthened time is due to the *interference* of associations that has resulted. If we were using the test series for diagnostic purposes, this would indicate a point to which further enquiry must be directed. Failure to respond or to reproduce is similarly interpreted. The information to be derived from the nature of the response depends partly upon the actual response given, and partly on the kind of associative bond which links it to the stimulus word. The response itself may obviously reveal the subject's thought content in an illuminating way, while the kind of the associative bond may show a thought tendency which has important diagnostic significance. For the science of psychology, however, the most valuable outcome of Jung's work in this direction has been a classification of associations, which, in its general lines, must be conceded to be

more useful than any other scheme of classification of associations hitherto suggested.

Classification of Associations.—One scheme of classification of associations that has had wide currency is based upon the assumption that the two primary laws of association are the laws of contiguity and of similarity respectively. Myers gives the scheme in tabular form as follows :—[1]

similarity	in meaning	co-ordination, e.g. baby—infant
		superordination, e.g. soldier—man
		subordination, e.g. man—soldier
		contrast, e.g. peace—war.
	in sound	in letters or syllables, e.g. port—porter.
		in rhyme, e.g. fight—kite
contiguity	in time	causal, e.g. lightning—thunder
		verbal, e.g. snow—snowball.
	in space	e.g. handle—lock.

While such a classification as this has its uses, it is neither psychologically adequate nor diagnostically very significant.

In Jung's classification " Inner " and " Outer " Association are substituted for Similarity and Contiguity. In the case of the former the associative bonds are real, intrinsic, thought-connections, in the case of the latter the connections are superficial, extrinsic, or merely accidental. In addition to these main categories, Jung designates certain types of association " egocentric," where the response implies subjective valuation in connection with the situation called up by the stimulus word. It is plainly possible to bring this under the head of " inner " association, if we recognize two sub-groups under " inner "—associations depending on thought relations, and associations depending on affective relations. Other types of association recognized by Jung may be treated in the same way, and brought under the head of " outer " associations.

A working scheme of classification, based on Jung's distinctions but utilizing also the scheme we have already given, would be something like the following :—

[1] *Text-book of Experimental Psychology*, vol. i., chap. xii.

- Inner (intrinsic) associations
  - thought system
    - causal relations
    - co-ordination, subordination, etc.
    - contrast
    - predicative
    - adjectival
  - emotion system
    - common affect
    - egocentric
- Outer (extrinsic) associations
  - mere contiguity in time or space
  - verbal contiguity
    - assonance
    - rhyme
    - word completion.

It is obviously impossible to classify associations independently of the subject's introspection. The connection that seems probable, when we look at the response from the outside, may be quite wrong. Thus it is impossible to say whether the association *health-wealth* is causal dependence, co-ordination, rhyme, or speech reminiscence (word completion), without information given by the subject.

Interference.—We have seen that the conclusions drawn from Jung's Association Test depend partly on the time of response, and that lengthening of the time is due to emotional disturbance. It frequently happens that the first idea called up by association is inhibited from expression by the subject, while he searches round for some other response. The search may be prolonged because of the influence of what is known as *interference*. The phenomena of interference are best brought out by a very simple experiment. If we arrange simple figures, like triangles, circles, squares, crosses, stars, in a series of lines, with the same number of figures in each line, but differently arranged, so that sometimes a triangle precedes a circle, sometimes it precedes a star, we shall find the phenomena of interference showing themselves whenever the subject tries to name the figures in each line as rapidly as possible. Although there are equal numbers of figures in all the lines, very unequal times are taken for the lines. Moreover, the subject will come to a complete stop every here and there. When asked what is happening, he will say that he finds it difficult and even impossible on certain occasions to get the name said, that he wishes to say, because another name persists in trying to get said. For example, the figure may be a square, and the word " circle " keeps coming to the tongue. It will generally be found that the reason for this is that the previous figure was, on the last occasion,

followed by a circle, or has frequently been followed by a circle, so that its naming tends now to be followed by the word " circle." In other cases there may be an actual competing of two names, neither of which is the right one, because of previous association. Such are the phenomena of interference. A lengthening of the time of response is always involved, and sometimes a failure to respond altogether. The phenomena also play a part in our ordinary mistakes and forgettings.

CHAPTER XIII

LEARNING AND MEMORY

"THE term learning is used to signify both the development of intelligence and the acquisition of muscular skill," so writes Ewer.[1] These two forms of learning are not independent of one another but are closely related, for intelligent learning is usually bound up with some form of motor skill, and motor learning is always more or less intelligent. A recent experiment carried out by Gopalaswami with mirror drawing bears out this very contention.[2] The subject was asked to trace a star-shaped drawing, not looking at it directly, but as it was reflected in a mirror. The movements of his hand were also observed in the mirror. Gopalaswami arranged his apparatus so that a record was automatically made of all the movements of the pencil (in this case a stylus), as it traced out the pattern, the pattern being divided up into 24 points. A metronome in circuit with an electric hammer regulated the rhythm of the movements, and only one movement was allowed with every stroke of the hammer. The investigator analysed the errors made by his subjects over a period of time. He found that the 500 errors made were divisible into two groups, which he designated as lower level, and higher level, respectively, according as the responses involved, or did not involve, any novel process. Further, he found that the higher levels of response were closely associated with intelligence and gave a correlation of ·81, and "that the responses of the lower level persisted longer in the subjects who were estimated as low in intelligence." [3] When the experiment was repeated under different conditions, so that opportunities to make responses of the higher level were reduced to a minimum, the results showed little correlation with

[1] *Applied Psychology*, p. 159.
[2] *British Journal of Psychology*, vol xv., pt. iii. [3] *Ibid.*

intelligence—only ·05. "This result is in good harmony with the view that the present procedure, by reducing to a minimum the subject's opportunity to judge the nature of his mistakes, thereby brought down his reactions to a low average level." The author asks how does this trial and error learning, which is "intelligent" learning, differ from that which commonly earns the latter name, and concludes, "that the trial and error and the intelligent learnings do, indeed, resemble one another in so far as both alike rely upon the processes of educing relations and correlates. But they differ from one another in that the trial and error operation is chiefly effected by conscious processes of low intensity, high speed, and wide distribution, whereas the intelligent operation is the reverse in all respects; the former may be called marginal, and the latter focal.

"This comparison between the two kinds of learning appears to be suggestive of many important consequences, both theoretical and practical. To begin with, the often asserted trenchant line between the two fades away into a perfectly continuous transition; marginality and focality are merely matters of degree."[1]

This experiment of mirror drawing is a typical learning experiment. Instead of results being recorded in the form of the number of errors made with each trial, the total time taken to trace right round the star may be the criterion of success, for usually the subject is allowed to work at his own rate of speed. This will show a decided decrease with each trial, until the limit of improvement is attained. The question now arises as to the cause of the improvement. What are the factors at work, effecting a saving in time and a diminution of errors? The fact that with every repetition improvement occurs, shows a practice effect. The common adage that "practice makes perfect," holds undoubtedly in this type of learning. The right responses are gradually strengthened, the wrong movements are one by one eliminated, and the element of chance diminishes by degrees. This is Thorndike's Law of Use. But this can only partially account for the improvement which occurs, for wrong movements are repeated with greater frequency than right movements. There must be, therefore, some other factor which will cause the correct responses to be strengthened in greater proportion than their frequency would lead one

[1] *British Journal of Psychology*, vol. xv., pt. iii.

to imagine. This is to be found in the feeling-tone accompanying each movement. A right movement produces a glow of satisfaction which is favourable for its stamping in and repetition; a false movement evokes dissatisfaction and an unpleasurable feeling, with the consequent impression that such undesirable reactions should be eradicated. This is Thorndike's Law of Effect. The Law of Use and Effect—for the two laws are usually combined together—plays the predominant rôle in all learning of this kind, learning by trial and error.

A brief description of a recent experiment devised by Pyle,[1] shows, perhaps, more clearly the nature of trial and error, or "haphazard" learning.

The apparatus consists of a cloth bag which is suspended from a wire ring six inches in diameter, the ring being supported 9 inches from the floor by three uprights fastened to a wooden base. The subject stands 12 feet away, and has to pitch 50 balls, one by one, into the bag. The score is the number of balls which enter and stay in the bag. Four series of 50 are pitched on the one day, and a second set on the following day, and so on, if an extensive experiment is desired. One subject carried out the experiment for 100 days, tossing 200 balls a day. His score ranged from 37 at the beginning of the experiment, to 102, the maximal score, near the end of the trials, after which a slight decrease became evident.

But trial and error is best demonstrated in all cases by animal learning. The maze experiment in which the animal is placed at the entrance and has to find its way to the centre where lies its food box, reveals this method of procedure in its simplest form. To begin with, random movements occur, the animal runs backwards and forwards in the many cul-de-sacs, and may actually cover every square inch of ground before his goal is reached, but it is wonderful the progress which is revealed with each fresh attempt, until, ultimately, it goes straight from the entrance to its food box in the centre. Here, again, practice, and satisfaction, reveal the cause of improvement. To set a human being down in a maze and ask him to reach the centre does involve trial and error, but in a much simpler form, for the individual has certain advantages which the animal lacks. To make the experience more comparable, Thomson[2] suggests

[1] *A Laboratory Manual in the Psychology of Learning.*
[2] *Instinct, Intelligence, and Character.*

that a maze be tried without actually looking at it. A friend is to read out at each entrance two letters, one indicating a blind alley, the other the correct route, the subject having to choose between them. The responses in each case are written down and repetitions given until perfection is reached. By this method, Thomson states, " You will certainly have more poignant feelings as to the laws of use and of satisfaction in maze-running than you would have otherwise experienced."

Trial and error learning is a wasteful method, for it involves many unnecessary movements producing fatigue and using up time. It is also discouraging, for improvement is gradual and is entirely due to chance. But, if the learner has some one whom he can imitate, or who is willing to show him how to tackle a problem, then much saving is effected. Learning by imitation is substantially the learning of children, hence the importance of having good examples for the children to follow. Trial and error learning cannot be dispensed with altogether, but observation gives a good start and it is because of the combination of these two methods that trial and error learning of humans surpasses that of animals. Little learning by observation appears in animals, although isolated cases have been reported. Köhler, for example, finds imitation existing in chimpanzees, but only as in the case of man, if the chimpanzees understand or are familiar with the action to be imitated.[1]

But the highest type of learning is learning by thinking, which seems solely characteristic of man, although, again, Köhler's results show intelligent thinking among apes. If we give an individual a mechanical puzzle to work out, then he may connect it up with previous puzzles he has solved, and may see similarities between them and the present puzzle which may guide him, and the result may be that he will think out the solution before he starts the actual manipulation. Further, a man is able to work mentally with objects which are not actually present, such as in practising scales on any musical instrument, and this ability gives to man a decided superiority over the animals.

Ewer [2] quotes an interesting case from Scott which shows the comparative value of the three methods in the solution of an intricate mechanical puzzle by four persons.

[1] See *The Mentality of Apes*, for a discussion and criticism of "trial and error" learning.

[2] *Loc. cit.*

The *first*, by trial and error, took eight hours, and only after several lengthy repetitions could do it quickly.

The *second*, having watched the first, did it in two hours.

The *third*, an expert mechanical engineer, studied the principles involved, and solved the puzzle in half-an-hour. Using his knowledge, he then taught the *fourth* to do it in fifteen minutes.

Habit.—When learning becomes permanent, it involves often the formation of a habit, and, as James expresses it, mankind consists of "bundles of habits." What is the practical value of habit formation?

1. To cite James,[1] the first advantage is that habit simplifies the movement required to achieve a given result, and produces less fatigue. It also saves time and energy. "If an act became no easier after being done several times . . . then the whole activity of a life-time might be confined to one or two deeds, and no progress could take place in development."[2]

2. The second result is that habit enables acts to be performed without attentive consciousness. For example, if a chain of events A B C D E have to be performed such as in the case of a child learning to walk, then these separate items have to be selected out from other irrelevant ones. At first the chain of events is detached and separate; the child breaks the sequence of the chain by making wrong movements, etc. Gradually, however, proficiency is attained until the chain of events is carried out as if it were one continuous movement. It tends to be carried out automatically, and no conscious attention is required. Habit, therefore, by rendering actions of the lower centres automatic, allows freedom for the higher centres to operate.

In the deliberate formation of a new habit, there are four essential rules which James lays down:—

1. The first step in the acquisition of a new habit is to launch out with as strong an initiative as possible. Accumulate all the possible circumstances which will reinforce the right motives.

2. Never suffer an exception to occur until the new habit is securely rooted, in other words, avoid exceptions.

3. Seize every possible opportunity for practice of the habit.

4. Keep the faculty of effort alive by a little gratuitous

[1] *Principles of Psychology*.
[2] Quoted by James from Maudsley, *Physiology of Mind*, p. 155.

exercise every day. As James expresses it, be systematically heroic in little unnecessary points.

We turn now to some of the more specific results which have arisen from detailed studies of the learning process.

The Learning Curve.—As we have gathered, progress in learning takes place as the wrong movements become eliminated and the right movements become strengthened. Does this improvement take place rapidly or is the process a gradual one? Suppose we were learning to use a typewriter and we allotted half-an-hour every day to practice, and counted each day the number of words we were able to type, then we could express our results in the form of a graph. This graph would

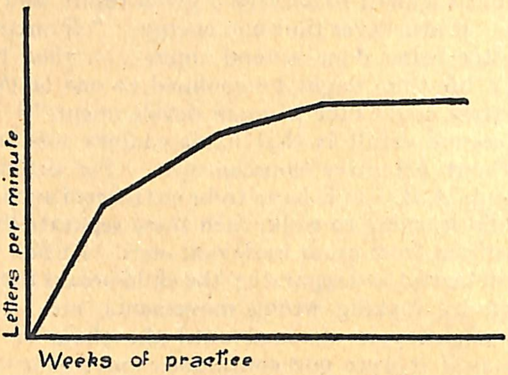


FIG 13.

give us what is called the learning curve, as in Fig. 13. This curve is a typical curve of all learning, either mental or muscular, which is extended over a fairly prolonged period of time. The curve itself consists of a large number of irregularities. These fluctuations are due to a variety of causes, such as inattention, fatigue, loss of interest, changes in physical condition, etc. The learning curve is shown better if these irregularities are smoothed out. This is done either by taking the average of every three periods of work and plotting the graph in this way, or it may be done as follows: Take the first score made and double it and add the second score. Divide the combined score by three, and this average gives the first smoothed score. To obtain the second smoothed score, add to the second score, the first and the third scores, and find the average. The third

smoothed score is the average of the second, third, and fourth scores, and so on. When the end is reached, the last smoothed score is the average of the sum of the last score but one combined with the last score doubled, as at the beginning of the curve.

In the learning curve, the first thing we notice is a rapid rise at the beginning of the curve, which is always present; then the rate of progress gradually slackens until a level of attainment is reached where further progress seems to be impossible (Fig. 13). This level of attainment is what is known as *a plateau* in learning. This plateau seems to mark the limit of progress for the time being, for even although practice is carried on, no

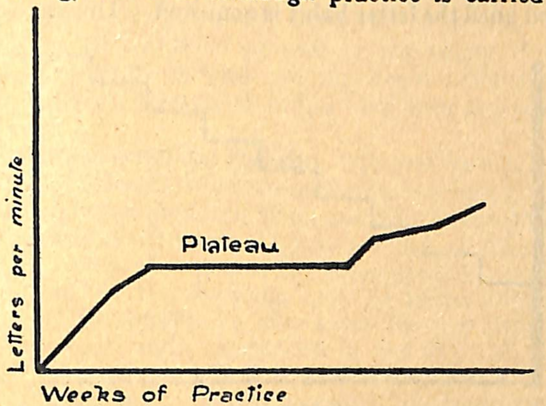


FIG. 14—(After Bryan and Harter.)

further advance is made. Kitson appropriately calls this plateau, "the plateau of despond." It is, however, a feature found in most cases of learning. If effort continues long enough—and this is the interesting point—this period of stagnation will be passed, perhaps, in a sudden burst of ability that will carry the individual to a much higher level of attainment (Fig. 14).

Plateaus may be due to various causes—discouragement, poor physical condition, lack of effort—or they may be caused by inattention which supervenes whenever a task becomes too easy. To advance beyond a plateau requires a special effort, and the effort must be made at the opportune time when the learner is ready for it. In school the teacher becomes invaluable

at this juncture to spur on the pupil to surmount the difficulty and advance from the plateau. The curve of learning extended over any length of time consists of a series of plateaus of steps, of which each, in turn, must be surmounted before a higher level of efficiency is reached (Fig. 15). Some become discouraged and never rise beyond the first level.

But the plateau may be given another explanation; it may mark the physiological limit of improvement, or it may mark the physiological limit as long as some particular method of work is employed, and what may be necessary may be an improvement in method. This is what happens in typewriting. To begin with, the positions of the various letters of the alphabet have to be learned until the letter habit is acquired. This marks the first

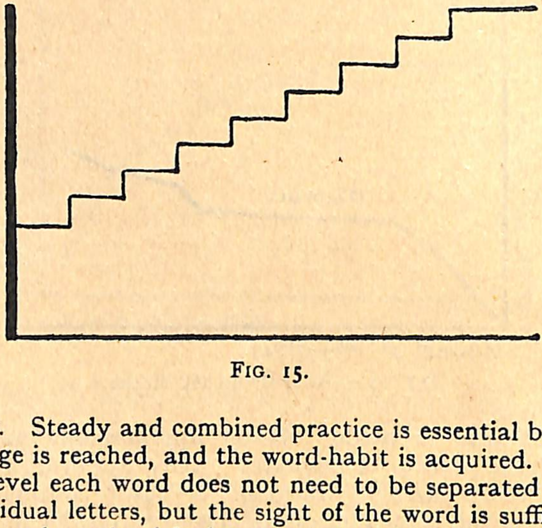


FIG. 15.

advance. Steady and combined practice is essential before the next stage is reached, and the word-habit is acquired. On this higher level each word does not need to be separated out into its individual letters, but the sight of the word is sufficient, as it were, to have it picked out automatically on the machine. A higher unit still is attained when the phrase habit is developed. Each level marks a definite stage in improvement, and each stage requires a certain period of time before it becomes automatic, and before a higher order can develop. The length of the plateau indicates the time required to make the lower units automatic. The plateau, therefore, is a necessary stage in learning, and if progress is hurried, retrogression may set in.

Another explanation which has been put forward as partly

accounting for the plateau, is that bad habits may have been acquired which are preventing progress, and which require elimination before any advance can be made. According to James, the majority of us never reach our physiological limit—we are content to remain at some plateau, and never make the special effort necessary to rise above it.

One very efficacious incentive to further progress is that of self-competition. It has been proved to be successful in the educational and in the industrial world. The individual endeavours to beat his previous day's record or his previous week's record. The industrial worker is anxious, if his progress in work is drawn out for him in graphic form, to make the curve rise higher, and similarly with the child at school. It gives the dull child an incentive as well as the bright child. The dull child has not to surpass the top boy's achievement, but endeavours to beat his own record, a task more in keeping with his abilities.

Distribution of Learning Periods.—Suppose we had to memorize a number of facts, and had so much time for repetition; would it be better to learn the facts all on one day, or should we distribute our repetitions over several days? The results of repeated investigations have shown that the more extended the distributions, the easier is the learning, and the better the retention. If there are eight repetitions, two a day for four days yield far better results than eight repetitions in one day. Accumulated repetitions, as Myers expresses it, are much inferior in value to distributed repetitions. A very excellent illustration is afforded by Starch's experiment. In a substitution test—substituting numbers for letters—four groups of subjects were employed. In each case the same total time was given, but distributed differently (Fig. 16). The first group worked for ten minutes at a time, and twice a day for six days; the second group worked for twenty minutes at a time, but once a day for six days; the third group worked forty minutes at a time every other day for six days; while the fourth group worked for two hours all in one day. The work of every subject was calculated in five-minute periods and set out in graphical form. The results show that the shorter and the more numerous the working periods, the better the work. It will be noticed from the figure that the twenty minutes group at one point surpasses the ten minutes group. This may mean that the economic interval of learning has been surpassed, and that a fifteen-minute interval

would have given better results, and sounds a note of warning that the period each day must be long enough to allow of adaptation.[1]

The difference in efficiency is not due entirely to fatigue, although that does play a considerable part, nor is it entirely due to the fact that the learner thinks over the material between the repetitions; but the benefit is derived from the manner in which the bonds of connection have been established. The difference in age of the associations is the potent factor. The older the association, the stronger it becomes with repetition. In concentrated learning, where we repeat the material over

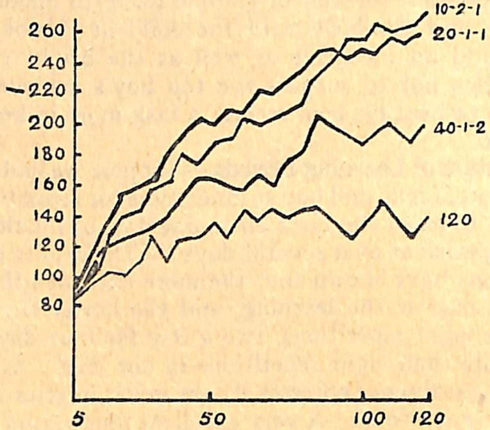


FIG. 16.

and over again at the one sitting, the first repetition is not sufficiently long established to be benefitted in this way. In distributed periods of learning spread over six days, the benefit of the first repetition is obtained six times over. Not only does age make an association stronger, but it makes its retention better. These facts give us Jost's Law, which he formulates thus: "When two associations are of like strength but of unlike age, repetition increases the strength of the older more than of the younger associations. When two associations are of equal strength, but unlike age, the younger fades more

[1] This experiment shows the fallacy of the so-called *intensive* course

rapidly than does the older." The same rule of distributed learning holds equally of motor learning or muscular activity, as of mental learning.

Another factor which serves as part explanation of the above phenomena is the effect of pauses and intervals in a learning period. A too long period of learning causes fatigue, but a pause inserted allows the effect of fatigue to pass away. Further, during a pause the bonds formed become consolidated, wrong bonds tend to disappear, and right bonds are more thoroughly established, so that distributed learning is more economical from every point of view than concentrated.

Methods of Learning.—Our next question is: What is the best method to be used in memorizing? The method most generally employed is to learn part by part, or if it be a poem, verse by verse. But it has been proved by investigation that such a method is not the most profitable. The most remunerative method is to learn the material as a whole. The poem must be repeated again and again in its entirety until it has been committed to memory. This "entire method" is good up to the length of 240 lines or so.

The reason for the entire method being better lies in the fact that fewer erroneous bonds are established. In learning poetry a verse at a time—the so-called "sectional method"—a connection or *bond* of *association* is formed between the last line of every verse and the beginning of the same verse. This is a bond which is quite useless afterwards, and has to be discarded. Usually, too, it is difficult after the verses have been separately learned to get the correct bond established between one verse and its successor, owing to the interference of the wrong bond. On the other hand, in the entire method, no useless bonds are formed except the bond between the end and the beginning of the poem, and consequently, no erroneous bonds have to be broken.

It is doubtful whether one can recommend the entire method for children, for discouragement is apt to set in when results are slow in appearing. As a matter of fact, this is one of the great disadvantages of learning by wholes. The glow of satisfaction when a verse of a poem is learned is an incentive to further endeavour, an incentive which is entirely lacking when the poem is read from start to finish each time. The most one can say with children is to give them as large units as they can tackle without losing self-confidence. This is borne out by the

recent experiments of Winch,[1] who advocates the part method as decidedly superior to the whole for children.

A second disadvantage to be cited against the entire method is that sometimes the material to be learned is not homogeneous. One part may be more difficult than another, necessitating a large number of extra repetitions of the whole in order to commit this difficult part to memory.

This lack in the homogeneity of the material has led to a modification in method, and the " mixed method " has been suggested. Adopting this procedure the learner begins at the beginning and proceeds until the first difficulty is reached, such as a complex meaning. A stop is made there until the difficulty is mastered. Then a start is made from the beginning again until the second difficulty is reached and overcome, and so on throughout the whole poem. Or all the difficulties may be mastered to begin with and the entire method employed. Gopalaswami, in his recent investigation of mirror drawing, apparently found the " progressive " method superior. In this the subject learned the first section, then the second, then the two together. The third section was now mastered, and the first, second, and third learned together, and so on.[2]

But learning, no matter what method is employed, is greatly facilitated if it is accompanied by the " will to learn." Indolent learning is a waste of time, and ten minutes' concentration is worth far more than ten hours' idling in supposed learning. Lax attention means poor results and little retention. One may repeat over and over a list of names or a series of figures, perhaps in dictating them to a second party, and find that not one can be remembered, simply because the intention to remember was not in consciousness. Further, interest in the material to be learned is a considerable aid to efficiency.

Rate of Forgetting.—Experiments have been carried out on the rate of forgetting. With every kind of material used, it has been found that forgetting takes place rapidly for a short time immediately after learning, and then proceeds very slowly. In fact, according to Ebbinghaus, half of the material learned is forgotten in the first half-hour, two-thirds in eight hours, and four-fifths in a month, a result of great consequence in the sphere of advertising. This rate of forgetting shows that recall in learning is beneficial, and that the best time for recall is shortly after the material has been learned, for that is the time

[1] *British Journal of Psychology*, vol. xv., pt. i. [2] *Ibid.*, pt. iii.

in which the rapid forgetting takes place. The general estimate given is that of the time spent in learning, half that time should be spent in recall.

Immediate and Permanent Memory.—So far, we have not differentiated between the two forms of memory which exist, and which may be described as immediate memory and permanent memory respectively. If the individual has to reproduce what he has learnt immediately after learning it, before there has been time for the matter to have left consciousness, then he is employing his primary or immediate memory. If an interval of time elapses between his learning and his reproducing, the permanent memory is involved.

The determination of the memory span is the method used for testing immediate memory. Usually, series of varying length, either of numbers or of nonsense syllables, are presented to the subject, the object being to ascertain how long a series can be reproduced after one repetition. Immediate memory has been found to increase with age, but at no time has the child's memory span attained the efficiency of the adult. Meumann found that the development of immediate memory is very slow up to thirteen years of age, from thirteen to sixteen there is a rapid advance, and the maximum is attained from the years twenty-two to twenty-five, after which there is a slight decrease. Immediate memory depends upon the factor of perseverance or perseveration, the ideas linger or persevere in the memory.

The investigation of the memory span is important from the point of view of education. In spelling, for example, it has been found that a child of seven can only remember six letters, therefore a spelling word of more than six letters may be an impossibility for the child unless it is grouped into syllables or units. The memory span may be tested visually or it may be tested auditorily. The words or digits may be shown one by one or they may be spoken to the subject. The auditory memory span forms a vocational test for many occupations, such as that of telephone exchange girls, where it is an essential qualification to have a good memory for figures presented auditorily.

The experimental methods employed in investigating permanent memory are three in number.

1. *The Learning and Saving Method.*—A series of nonsense syllables or of digits is arranged beforehand, usually on a cylinder of some kind. This cylinder forms part of a " memory

apparatus," and is so affixed that when the mechanism is set agoing, only one nonsense syllable or one digit appears at one time behind an aperture. The series is shown in a regular rhythm. The subject, with the eyes on the level of the aperture, says aloud each digit in turn, until the series is finished. Then an attempt is made to reproduce. If unsuccessful, the series is shown once more, and so on, until the subject can produce the series correctly and in regular order. This constitutes the learning method. After a lapse of time, a day or two days, or even a week, an attempt is made to reproduce the same series, and if errors occur, relearning must take place. The difference in the number of repetitions necessary for relearning constitutes the saving.[1]

2. *The Prompting Method.*—In this method the series is imperfectly learned and the reproduction is measured by the number of times the subject requires to be " prompted " before complete reproduction takes place.

3. *The Scoring Method.*—In this method a series of nonsense syllables is presented a prescribed number of times, not enough to ensure complete learning. With each repetition the subject reads the series in trochaic rhythm, so combining each two successive syllables into a pair. After an interval of time, the first of each pair of syllables is shown to the subject in irregular order, and he is required to reproduce the other member of the pair. The number of correct reproductions constitutes the score. By means of a chronoscope arrangement, the time taken by the subject to recall the second member of each pair may be ascertained. This is known as the scoring time.

In all these experiments it will be noted that either digits or nonsense syllables ought to be employed. This is necessary, because in all learning experiments the material to be learned must be made as simple as possible to keep conditions constant. If " meaningful " material is used, the results from different individuals will not be comparable. Examples of nonsense syllables are: *dak*, *puw*, *zid*, *taf*, etc.

Conditions determining Permanent Learning.—All learning seems to consist in the formation of bonds or associations. But some bonds are more easily made than others, and therefore there must exist certain conditions which favour the retention of some associations and the dropping out of others.

[1] This method may be carried out quite simply without any apparatus.

The value of the factor of perseveration is not so great in permanent learning as in immediate learning, and yet in certain circumstances it is important. The constant "ringing" of a tune in the head is due to this factor which may be described as the spontaneous revival of any experience without effort being expended.

The operation of association, fully discussed in the previous chapter, has the main influence in deciding what is to be remembered and what forgotten, and also the factors of primacy, frequency, recency, and vividness or intensity. An additional factor is that of *retroactive inhibition*. It is a well-known fact that associations, when made, require a certain time to set. If that interval of time is not forthcoming, and some new association formed, interference sets in and we say that the first bonds are retroactively inhibited. The insertion of a pause is always advisable. This inhibition phenomenon is best seen in language habits. In following a lecture, the listener has scarcely grasped one point and assimilated it before the speaker has gone on to develop his next argument. Pauses are profitable, from the point of view of both listener and speaker. They aid the former in retention and the latter in exposition.

Interference may take place in motor learning also, and is excellently shown in the card-sorting experiment of Pyle. A tray is divided into 30 compartments, with each square or pigeon-hole numbered from 11 to 40 in irregular order. The subject is handed a pack of cards, all thoroughly shuffled, containing the same numbers, each repeated five times, and is asked to place each card in its corresponding pigeon-hole as rapidly as possible. The experiment is carried out for a number of days until the position of the numbers seems to be completely established. Then the tray is turned over, exposing a similar arrangement of compartments, but with the numbers exhibited in a totally different order. The habits formed in the first experiment interfere with the formation of this new set of habits.

The effect of interference may be seen in other ways. It may be that so many associations are formed that they block each other's path. Or if in learning the first attempt has been erroneous, we may find it difficult to get rid of it, and this wrong start will persist in coming up into consciousness and frustrating all further attempts. It is important, therefore, to make a good beginning.

CHAPTER XIV

IMAGINATION AND THE HIGHER THOUGHT PROCESSES

AS far as the mental content consists of trains of imagery we may speak of the mental process as *imagination*. This is not the ordinary use of the term. Popularly remembering and imagining are taken as two distinct types of mental process, the one being merely reproductive of what has been experienced in the past, the other being definitely constructive of what has never been experienced; the one, that is to say, being, as it were, bound down to a real past event, the other being free from any such constraint. Both are, however, but sub-types of the one general mental process, as are also the process we call expecting or anticipating, and in some aspects even the process we call planning or purposing. In all these cases the mental content consists of trains of imagery, and so far the process is imagination. Imagery itself has already been discussed, as also reproductive trains of imagery. Nevertheless, there are still various phenomena of imagination remaining to be discussed.

There are two very important aspects of imagination. These we may call *fertility* and *constructive ability*. In neither case can we say that adequate experimental work has been performed. The problems that arise present very considerable difficulties. Nevertheless, a certain amount of work has been done, and the future will doubtless see development and expansion of such work.

Fertility of Imagination.—Fertility of visual imagination has been investigated by what is called the "ink-blot" experiment. The experiment was first carried out by Binet and Henri in 1895. The material has been standardized by Whipple,[1] in

[1] *Manual of Mental and Physical Tests*, vol. ii., p. 254.

the form of 20 "ink-blots." With Whipple's material either of two procedures may be followed. In the first method of procedure the subject is asked to look at each "ink-blot," taking his own time and trying it in different positions, and to write down all the things he can see, or rather imagine, in the "ink-blot." In the second method of procedure the 20 cards are arranged in a pile, face downwards, and the subject is instructed to turn over the first card on a signal from the experimenter, to look at the "ink-blot," and to say "now," or tap on the table, as soon as it has suggested some picture. A stop-watch is started by the experimenter when he gives the signal, and stopped when the subject says "now" or taps on the table to signify that a picture has come. In the first procedure the result is based on the total number of pictures suggested, in the second on the average time taken for a single picture to present itself. These results are in both cases quantitative, but interesting qualitative differences between individuals are also shown by the kind of pictures suggested.

This test is called a test of the fertility of *visual* imagination. It is difficult to say how much stress should be laid on the word "visual." It is by no means easy to see how material can be prepared and standardized for investigating fertility of imagination in other sense departments. On the other hand, we dare not take the results of this experiment as evidence for fertility of imagination in a general sense.

Constructive Ability.—What has just been said regarding fertility of imagination holds with even greater force regarding constructive ability. Nearly all the rigorous experimental work has been limited to a narrow field—the field of linguistic invention—and the results must be interpreted with reference to this field alone.

Several varieties of method have been employed. The most familiar method is that which has been named after Masselon, who first used it, the "Masselon Method." This consists in giving the subject certain words—usually three—and asking him to make sentences, each containing all three words. The words given may be either nouns or verbs. Five minutes should be allowed for each set of words, the subject writing as many sentences as he can in the five minutes. The number of sentences gives a quantitative result, but a qualitative estimate is not quite so easily obtained except in a more or less crude way from the quality of the sentences given. Meumann

modified this method by using only two words so selected that only one relation between them is appropriate—or at least only a very few relations. In so doing he made a better test of intelligence, but a worse test of imagination.

Another method that may be used is that of sentence completion. Binet's experiments with his two daughters by this method are very well known. The subject is given the beginning of a sentence, and required to complete it. Characteristic differences were found by Binet in the way in which his two daughters responded to this experiment. Not only were there differences in speed, but there were also marked differences in the nature of the completions given. For example, the one completed the sentence "I entered . . ." by writing "I entered the field by a covered footpath," the other by writing "I entered the grocer's shop and bought a pennyworth of chocolate." When a quantitative result is sought in this experiment, we give the subject a blank with the beginnings of twenty-five sentences, expose these one at a time, and take the time in each case from the exposure till the subject begins to write the completion.

The "Completion Method" of Ebbinghaus may also be taken as partly a test of constructive ability, though it is to a much greater extent a test of intelligence, in the narrower popular sense, than of imagination. In this method the subject is presented with a continuous passage in prose, with certain words or phrases omitted, which the subject is asked to supply. A method, which may be described as the converse of this, is to give the subject certain words, and ask him to write as long a story containing them as he can. This is a modification of the linguistic invention test which may obviously throw much light upon a subject's imaginative ability. It is clearly a better test of the kind of constructive ability we wish to investigate than the Ebbinghaus method, but to obtain quantitative results from it is somewhat difficult.

Finally, "word-building" has been suggested and employed as a method of testing constructive ability. In this case the subject is given six letters, and directed to make as many words as he can with these letters, using as many or as few of them as he likes, but using no letter twice. A time limit of five minutes is imposed, and a quantitative result is obtained by counting the number of words made in that time.

The Thought Processes.—The reproach has frequently been

directed against the advocates of experimental psychology by the representatives of the older philosophical psychology that experimental methods have a very limited applicability in the study of the mental life of the human being, and in support of their contention the latter almost invariably cite the higher thought processes as an admirable illustration of the limitations of experiment. The reproach is hardly justified by the facts of the situation. It is true that experimental methods have met with very limited success, when applied to the study of the higher thought processes, but the same can be said with even greater truth of the older methods of study. It is quite certain that a psychology which is not experimental is to-day an anachronism in any department of the mental life. In the case of the higher thought processes the employment of experimental methods has at least made clear what the psychological problems are, and has at least defined the limits of psychology, as distinct from logic and the theory of knowledge, whereas the older philosophical treatment mixed up the whole three together, so that it was quite impossible to say where the psychology of the thought processes began and where it ended.

The experimental study of the thought processes has sought in the first instance to define more clearly the nature of thought. In carrying out this task the perennial problem of imageless thought necessarily emerges, whenever the psychologist comes to consider the mental content—what is before the mind—in thinking. This has, in fact, been a problem for psychology since the time of Aristotle. In pursuing the enquiry whether the soul was separable from the body, Aristotle came to the conclusion that, if any functions of the soul were capable of being carried on without bodily organs, then so far the soul was separable, and capable of existing separate from the body. Thought would appear to be such a function, if thought is possible without imagery. Hence the importance for him of the problem of imageless thought. His finding was that, though there is nothing in the nature of thought itself demanding bodily organs, yet in actual fact thought in the human being is never without images, and since images depend on sense percepts, and therefore sense organs, thought in the human being is not actually carried out without bodily organs. Practically every psychologist since Aristotle has come on the same problem of imageless thought in some form or other, whenever he came to discuss the higher thought processes. Sometimes the question

has presented itself in the same shape in which it presented itself to Aristotle. At other times it has taken the form: How does the concept exist in the mind, or what is the nature of the concept as a mental fact? Essentially the psychological problem has always been the same.

Now *thinking* may be described as the conscious adjustment of an organism to a situation, with the emphasis on "adjustment" as well as on "conscious." Described in this way, thinking may obviously take place at all levels of mental life, perceptual, ideational, and conceptual. It is therefore also obvious that several of our preceding chapters have already dealt with phases and aspects of thinking. This is notably the case as regards the chapters on "Action" and "Perception." When we speak of thinking, however, we generally refer to such processes as judging, comparing, reasoning, and the like, and it is the psychological analysis of these processes by means of experiment that we must now proceed to consider. It is "conscious adjustment" involving what we call *conceptual* process.

Conceptual process represents the third or highest level of mental life—the *intellectual* or *rational* level. The essential characteristics of this level are two: (1) the thinking of relations; and (2) the apprehension of the general and abstract, as opposed to the particular and concrete. The step from reacting towards a relation between two factors in a situation to thinking the relation appears at first glance a very slight one. Nevertheless, it marks that phase of mental process, which is characteristic of the human mind, and the relative absence of which is equally characteristic of the animal mind. The first step in conceptual process involves a selective dwelling upon parts or aspects of a concrete particular situation—an analytic phase—and in thinking the relation, a relating of parts or aspects to the situations of which they are parts or aspects or to one another—a synthetic phase. As conceptual process develops it becomes possible in conceptual analysis, not merely to think an aspect in relation to a whole, but to hold the aspect in thought apart from the whole. This is the process of *abstraction*. Along with this goes the possibility of placing objects side by side in thought, and *comparing* them in respect of different aspects or qualities, and comparison, in turn, leads on to *generalization*.

One of the earliest experimental studies of these higher processes was that undertaken by Ribot in 1891, the results

of which are elaborated in his work *The Evolution of General Ideas*. He wished to determine what was in consciousness on reading or hearing a general term. The experiment was conducted in the same way as the "Word List Method" of studying imagery, which has already been described. Ribot's subjects divided themselves into three groups:—

1. A group having visual or motor imagery of an object—called by him the *concrete* type.

2. A group reporting a visual image of the printed word—called by him the *typographic visual* type.

3. A group reporting no imagery of any kind—called by him the *auditory* type.

A large proportion of his subjects belonged to the third group. His designation of these as the auditory type is quite unjustified. They said they had nothing in the mind at all. He argued that this could not be taken literally. The word at least must have been in consciousness, and if the word was understood there must have been something more. Otherwise there would be no difference between an understood word and a word in an unknown language. He concluded that this something more must have been unconsciously represented. As far as it goes the experiment gives evidence in favour of the view that imageless thought is possible.

The process of abstraction was also investigated by Moore by means of a recognition experiment. He employed groups of geometrical figures, in which one figure was repeated in varying position with regard to the others. The subjects were instructed to look for the repetition of a figure, and to stop the exposure apparatus when they felt certain that one had been repeated.[1] Aveling studied the same problem by means of a learning experiment, in which nonsense-words of two syllables were exposed along with pictures.[2] Both these experimenters reported in favour of imageless thought. It is obvious that in all these experiments the introspection of the subject is of chief importance. For this reason little reliance can be placed on the introspections of inexpert subjects. This being so, a new source of error must be taken into account. That is an unconscious bias in favour of some particular view. It would, perhaps, be better to say the unconscious influencing of introspection error

[1] *The Process of Abstraction* (Univ. of California Publications).
[2] *Consciousness of the Universal*, pt. ii.

by a bias, which may itself be quite conscious, in favour of some theory of thought. It is rather suggestive that experiments carried out in the same laboratory, and under the influence of the same chief, tend to be strikingly similar in the results obtained.

A series of investigations carried out in Külpe's laboratory at Würzburg must, perhaps, be regarded as more typical of experimental work on the thought processes, both as regards problems and as regards methods. These investigations began with the work of Marbe. His problem was the determination of the psychological nature of the process we call judgment, which he took to be the fundamental and elementary type of thinking. The procedure he employed was simple. He asked the subject to perform a simple task involving judgment, and then to give a careful introspective account of what passed in his mind. In the first series of experiments the subject had before him two objects of the same size and shape, but differing in weight. He was asked to lift them in turn, with the same hand, to the same height, and then to invert the heavier one. In another series the subject was asked to listen to a tone, and then to attempt to reproduce it as accurately as possible. In other series he was asked to add together two numbers called out by the experimenter, to answer specific questions, and so on. In all cases the introspection was the main thing, and the period of each experiment was fractionated to make it as detailed and accurate as possible.

Marbe took as his definition of a judgment " a conscious process to which the predicate right or wrong can be significantly applied." This is, of course, a logical, not a psychological, definition. The results of his investigation led him to the conclusion that there are no psychological conditions of the judgment as such, and this, in turn, led him to modify his view of the nature of judgment, so that he asserts that " all experiences may become judgments, if it lies in the purpose of the experiencing subject that they should accord, either directly or in meaning, with objects." More significant than this finding are some of the phenomena which come to light in the introspections of his subjects, and which other workers in the laboratory at the same time, who were working on association, also came across. These were the phenomena called at Marbe's suggestion " conscious attitudes " (Bewusstseinslagen). These were mental processes which refused to be described as either ideas or volitions.

The next group of workers on the problems—Watt, Messer, and Ach—employed somewhat different methods. The first of them was Watt. He employed partially constrained association experiments. A word was exposed visually, and the subject was required to respond with a word standing in a definite relation to the stimulus word. Three types of relation were employed—co-ordination, subordination and superordination. The chronoscope was used to take times, and systematic introspection was directed to four phases in the total experiment —the preparation period, the appearance of the stimulus word, the search for the response, and the response. Watt found the essential element in the act of thought or judgment to be the task (Aufgabe). In other respects also his results confirmed the results of Marbe.

Messer continued Watt's work, and at first by the same methods, except that he used free association in place of partially constrained. Later he passed on to partially constrained association, and later still to wholly constrained. This meant really a change of method. Just as the Word List Method had given place to the Association Method, so the Association Method gave place to the Mental Test Method, as we may call it, for that is what constrained association came to mean, if not in the hands of Messer, at any rate in the hands of his successors, at Würzburg and elsewhere. Bühler, who carried on the work on the thought processes at Würzburg after Messer, maintained that it was necessary to make the subject *think* if we wished to study the thought processes. In order to secure this end he presented the subject with specific questions demanding thought. Bühler claimed to have determined the nature of the "conscious attitude" which his predecessors had found. It involves, he concludes, a consciousness of the processes of thought itself. He, also, comes quite definitely to the finding that thought may be imageless.

We cannot here discuss the findings of these investigators with regard to the nature of thought, and the possibility of imageless thought in particular. What we are rather concerned with is the development of experimental methods for the study of thought. As we have pointed out, Bühler's method was practically the method of Mental Tests, and workers elsewhere, like Binet, Woodworth, and Spearman, have in the main used this method. The last two have made considerable use of tests involving conceptual process, such as the "analogics"

test, or the "syllogism" test. These mental tests, of which more must be said in a later chapter, involve relational thinking, and would, therefore, seem to be specially adapted for the experimental study of the higher thought processes. It is very doubtful, however, whether in practice they yield better results than the association method, as regards the general problem of the nature of thought, or than Ribot's word list method, or Aveling's learning method, with respect to the problem of imageless thought.

Very important work on the thought processes of children has recently been done by Piaget. This work includes a study of children's questions at different stages of development, and of the judgment and reasoning of children. It is described in Piaget's books, *The Language and Thought of the Child*, *Judgment and Reasoning in the Child*, and *The Child's Conception of Causality*. The whole is a very valuable contribution to child study and to our knowledge of the development of the thought processes.

CHAPTER XV

LANGUAGE AND ITS DEVELOPMENT

IT might be said that the biological function of language is to enable human beings to communicate with one another in order to secure co-operation in tasks which one individual cannot accomplish single-handed. Intercommunication is secured because language makes it possible for one individual to guide and control the thought, and so the external behaviour, of another individual. Language also makes it possible for an individual to guide and control his own thought processes. The guidance and control in both cases depend on the same conditions, and an investigation of these conditions leads us to an understanding of the psychological nature of language and its fundamental psychological functions.

Fundamentally, language is an instrument of conceptual analysis and synthesis. By means of individual words or signs the aspects or partial features of concrete perceptual or ideally represented situations are singled out, and, as it were, fixed. This is conceptual analysis—analysis into concepts—each word or sign representing a concept, or a product of conceptual process. Then, by the order and succession of the words or signs, the situation can at any time be ideally reconstructed, either for our own purposes or for the benefit of another. This is the conceptual synthesis, represented normally in our spoken or written language by a sentence or succession of sentences. The concrete particular situation is built up again out of the concepts, one word limiting or determining the meaning of another.

For example, if A says to B: "A red book was lying on the table," he has analysed a perceptual situation into its conceptual aspects and elements, "red," "book," "table," "was lying," "on," and, by the spoken sentence, enables B to reconstruct the situation in idea. Such is the characteristic psychological

function of language, and this function may serve as a test for its presence or absence. Ability to make language sounds in the case of the child, as in the case of the parrot, does not necessarily imply ability to speak. Only when the sounds, or other signs, perform the psychological functions of conceptual analysis and synthesis, can we say that language is present. This, of course, implies that conceptual process is necessary before language can come into existence, and it is equally true that language is necessary before conceptual process can develop.

A further characteristic of language is that it is a system of *expressive* signs. Stout has defined a "sign" as "some action or perceptible result of previous action expressly intended for communication of ideas to self or to others."[1] This definition is somewhat restricted. It covers, it is true, language signs and signs of an analogous nature. But it does not cover all kinds of signs. We might, perhaps, define a sign psychologically as "some experience, the main function of which is to call to mind some object, idea, or line of action—the meaning." There are different kinds of signs, as Stout has pointed out. A *demonstrative* sign is a sign the aim of which is to call attention to some special part or element in the perceptual situation. A *suggestive* sign is a sign the function of which is to call some idea to mind, which thereafter can be appropriately dealt with without further use of the sign; that is, the function of the sign is completely fulfilled in calling to mind. A *substitute* sign is a sign which can take the place of the idea or meaning for which it stands, and which, therefore, enables us to dispense with the need of keeping its meaning in mind. An *expressive* sign is a sign the function of which is to keep its meaning before the mind. Language, then, is a conventional system of expressive signs, functioning psychologically as an instrument of conceptual analysis and synthesis, and practically as a means of intercommunication between individuals.

In the functioning of language three kinds of process are involved. In the first place there are the motor processes involved in producing the signs. These are highly co-ordinated movements of groups of muscles. Movements are the natural vehicles of expression, and the high degree of control which we can exercise over movements—whether actual movements or imagined movements—implies a high degree of control over

[1] *Groundwork of Psychology*, p. 148.

language. In the second place there are sensory processes: (*a*) representing the receptive side of the language function; and (*b*) guiding and directing the muscular co-ordinations. Normally, the senses used are vision, hearing, and kinæsthesis, but, under special conditions, as in blind-deaf mutes, touch may take the place of the first two. In the third place there are interpretive processes, in so far as the language is understood.

The normal civilized human being possesses two language systems, the system of oral speech, and the system of graphic language. In their evolution these two language systems at first developed independently from that magma of imitative sounds and gestures, to which we must look for the earliest beginnings of language. Sounds, eked out by gestures, were employed to communicate with those present or near at hand; drawings, representing objects, actions, etc., were employed to communicate with the absent, and these must be considered as, in principle, direct imitations of the objects or acts, without any reference to the sounds by which they were indicated. Oral speech and picture language coalesced to form one language system when drawings or graphic signs were employed to represent, not objects, but sounds in the oral speech system.

The experimental investigation of language has followed two main lines, corresponding to the two language systems. On the one hand, there has been a study of the development of speech in the child, concentrating mainly on the development of the child's vocabulary. On the other hand, there have been investigations covering various aspects of graphic language, both in its production and in its apprehension and comprehension—that is, both with respect to writing, and with respect to reading. In addition to these main lines of investigation belonging properly to the sphere of experimental psychology, there has been considerable study of disorders of speech, which is of sufficient interest for the experimental psychologist to be briefly noted here. The various lines of investigation will be treated in turn.

Development of Speech in the Child.—Many investigators have studied the development of speech in the child. Part of this study has been concerned with the development of speech sounds, but that is relatively of much less importance than the study of the development of real language. Students of this aspect of child development have recorded the extent of the child's vocabulary and its nature, together with the types of

sentence structure, at various periods of the child's development. For vocabulary study two methods are available—what we might call a *catalogue* method and a *sampling* method. In the first case we record every word employed by the child whose vocabulary is being investigated, over a definite period of time, sufficiently long to allow approximately the whole vocabulary to be recorded, but not so long that the record from day to day represents merely the normal daily increase in vocabulary. A period of about a fortnight might be suggested as most suitable. Normally, this method can only be employed with children up to about the age of six or seven, owing to the fact that after that age the vocabulary has usually become too extensive for such a method to be practicable. Beyond the age of seven, then, we must, perforce, use the sampling method.

In the sampling method, the subject is presented with a list of 100 words, which must represent a fair sample of the words in the ordinary dictionary. He is asked to mark the words he knows the meaning of, or could use. The percentage of words marked may be taken as a first approximation to the percentage of the words in the ordinary dictionary known by the subject. To obtain a more accurate estimate, however, we must apply a correction factor to determine the words the subject actually knows as distinct from those he thinks he knows. This correction factor is obtained by taking the last ten words marked by the subject, and asking him to define or use each of them. The proportion correctly defined or used is then applied as a correction factor to the number marked. Thus, if the subject marks 80 of the 100, and defines correctly 9 of the 10, his total vocabulary is given by 9/10 of 80, that is, 72 per cent. of the words in the dictionary. If the number of these is 20,000, his vocabulary is 14,400 words. For a reliable estimate of vocabulary by this method we should take at least three samples, and average the results.

The sampling method has been employed by Terman in his revision of the Binet Tests as one of the tests, but in a somewhat different form. The words are arranged in what is intended to be their order of increasing difficulty, in two parallel series of 50 words each. Definitions are required. If the experimenter wishes to save time a single series of 50 words may be used. To get the total vocabulary of the subject, we multiply the number of words correctly defined by 180, or if the shorter list is taken by 360.

Somewhat interesting results may be obtained by classifying the words obtained from children at different ages under the parts of speech. While different investigators have obtained rather conflicting results, it seems clear that with the expanding of the child's environment there is an increase of nouns relative to other parts of speech, that increase of verbs indicates increasing range of conscious control, and that certain of the other parts of speech, such as pronouns, prepositions, and conjunctions, are significant of definite levels of intellectual development. Some investigators have also recorded, in place of the individual words, the sentences used by the child. This, perhaps, gives a still better idea of the language of the child, and the increase shown in the average number of words in the sentence, as in the complexity of sentence structure, with increase in the age of the child, is very notable.

Graphic Language.—As we have already indicated, graphic language has two aspects—its production and its apprehension, or writing and reading. Considerable work has been done in the psychological analysis of both aspects. The psychological analysis of reading, so far as the psychological laboratory is concerned, has, in the main, concentrated attention on three points: (1) the recognition of words; (2) eye movements in reading; and (3) speed of reading, and the conditions determining it.

The recognition of words in reading is investigated by means of the tachistoscope. The main problem first emerged in the form: do we read by recognition of the individual letters or by recognition of word-wholes? Evidence from pathological cases of disturbances of the language function seemed to indicate that we do not read by individual letters. The earliest experiments appeared to confirm the view that we read by word-wholes. Later work has, however, qualified this finding to a considerable extent. It has been shown that in the recognition of the total word-form certain characteristic letters or letter-groups play a dominant part. It has also been shown that in actual reading the context of meaning has considerable influence on the final recognition of a word, though there is what one may call an incipient recognition preceding this final recognition, which is largely determined by characteristic letter-groups or characteristic word-forms.

The study of eye movements in reading is an admirable illustration of the development of elaborate technical methods in this field. The eye movements of a reader can be studied

by direct observation. This at once reveals the fact that the movements are not continuous like the reading, that there are short jerky movements, alternating with pauses, as the eye passes along each line, with a longer swing backwards to the beginning of the next line, as each line is completed. The movements can also be easily followed by an observer by placing a mirror in front of the subject. In this case a record of the movements can be made by making a dot for each short movement and a line for each longer backward swing. Huey [1] studied the eye movements by anæsthetizing the surface of the cornea, and placing on it a small ring, with a light lever attached, so that the movements could be recorded on a smoked surface. With this method the movements and pauses could also be timed by marking a time record on the smoked surface simultaneously with the recording of the eye movements. Dodge carried elaboration a step farther [2] by photographing the eye movements on a plate sliding vertically. By interrupting the light focussed on the eye, by means of which the photographic record was obtained, the interruptions being made by a vibrating tuning-fork, he was able to record also the time of the movements and fixations. All investigators have found that practised readers fall into a definite habit of eye movement, the number of movements and fixations varying with the length of the line and the nature of the matter read.

The rate of reading varies enormously in different individuals, and with different kinds of reading matter. With light reading matter the range is from about 3·5 words to 15 words per second. Some early investigators found that the quicker readers were also able to reproduce more of what they had read than the slower. It is very doubtful whether this finding is reliable. Unpublished researches by one of the authors seemed to indicate that the amount reproduced did not vary directly as the rate of reading, but rather was independent of it. The main cause of slow reading with educated adults would appear to be the inner speech. Sometimes, with very slow readers, every word is actually whispered. On the other hand, with very fast readers, the inner speech is a mere skeleton, if it exists at all. One very fast reader in the investigation just mentioned claimed that there was no inner speech at all in either auditory or motor terms.

[1] *Psychology and Pedagogy of Reading*, p. 25.
[2] *Psych. Rev. Monograph Supplement*, viii.

The experimental investigation of writing has pursued a course more or less analogous to that of reading. The act of writing involves complex muscular movements and co-ordinations. There are movements of the fingers and wrist, together with movements at the elbow and shoulder joints. Rapidity, accuracy, and precision of movements of the fingers, wrist, and forearm have all been investigated, in part independently of the study of writing. Similarly, motor control, as indicated, for example, by ability to hold a metal stylus steadily in a small circular hole, without touching the sides, has been studied with reference to other problems than those of writing. All such studies have an obvious bearing on the mechanics of writing.

A specific investigation of writing movements, which is of considerable interest, was carried out by Judd.[1] Judd devised an apparatus by means of which finger and hand movements in writing could be separated. A writing point was attached by a U-shaped spring to the fifth metacarpal of the writing hand. In this way, while the subject was writing a word, the share of the hand in the total movement was shown alongside of the actual writing, and a comparison of this with the writing indicated the work done by the fingers. The only component of the hand movement that cannot be recorded by Judd's apparatus is the rotation movement in pronation. The work of the fingers varies with the writer, with the instrument, and with the speed.

Several investigators have also studied pressure in writing, and particularly the pressure on the writing point. Such study has a very distinct bearing, not only on the psychology of writing, but also on the study of defective and feeble-minded children, and on the study of the effects of drugs on motor co-ordination. In general, the apparatus employed has recorded the pressure on the writing surface. Kraepelin employed what he called a "Schriftwage," consisting of a plate supported by springs, the pressure on which was recorded on a smoked surface by a lever mechanically connected with it. Meumann got his pressure curves by resting the writing plate on an air-cushion, pneumatically connected with the recording lever. Drever recorded pressure from the writing instrument itself, by receiving the pressure of the top end of pen or pencil on a receiving tambour.[2]

[1] *Genetic Psychology for Teachers.*

[2] *Proc. of the Royal Society of Edinburgh*, xxxiv. The paper also gives some account of studies of *grip* pressure in writing, a field that has scarcely been touched.

The pressure curves given by adults and children respectively show characteristic differences. With adult writing there is a more or less rhythmical increase and diminution of pressure, whereas this characteristic is entirely absent with children before the age of about eleven. Moreover, the pressure curves show that the adult writes a word with a single impulse, while a child has a separate impulse for each letter, and sometimes for each stroke. The child is, in fact, drawing, not writing. Both these characteristics are due, on the one hand, to the course of development of co-ordination of movements, on the other hand, to the fact that writing is a form of language, and the psychic impulse is, therefore, an impulse to *write* a word, not to *draw* a line or letter. The rhythm in writing is analogous to the rhythm in speech, when real writing has developed.

The inner speech which usually accompanies writing has been found to be curiously complex. Continuous speech, carrying the meaning, appears to go in front of the writing, but seldom farther than the completion of the sentence that is being written. We are also usually conscious of the words as we write them, and of the words we are about to write. Lastly, there is an inner accompaniment of the writing, which would seem to consist generally of the repetition, often with distinct consciousness of articulation, of the elements of the words, or at least the prominent elements of the more important words. Slips of the pen in writing may often be traced to their source in this complex inner speech.

Disorders of the Language Function.—Neurology and psychopathology have contributed significantly to our understanding of language and its mechanisms by the study of the various disorders of the language function. Such disorders may be classified under three heads, representative of the three types of process involved in normal speech. In the first place there are disorders and defects of articulation, or generally of the mechanism of speech production—*dyslalia* or *dysarthria*. The commonest form of defect coming under this head is stammering or stuttering. Apart from other causes producing this disorder, Ballard[1] has brought forward evidence to show that a not negligible cause of temporary disorder at least is the attempt to compel the left-handed children to write with the right hand.

[1] *Journal of Experimental Pedagogy*, vol. i., p. 298.

Coming under the same head are cases of mutism resulting from congenital deafness. In the second place there are disorders and defects, either on the sensory or on the motor side, affecting the apprehension or the production of language, but not of sounds—*dysphasia*, or more usually simply *aphasia*. These disorders are due to lesions in the cerebral centres for speech, and have been classified as sensory or motor, and cortical, subcortical, or transcortical. In the third place there are disorders in the interpretive functions—*dyslogia*. These cases are generally included under the general head of aphasia, but they necessarily involve mental defect, and simple aphasia need not, at least theoretically. There is a form of defect in children, in which speech fails to appear, although there is no deafness and no paralysis of the organs of speech. This has sometimes been called *congenital aphasia*. These cases frequently develop speech very late, retaining marked articulatory defects.

Comparatively simple tests will enable us to determine in a preliminary way the type of language defect present in any individual case. We test whether the individual :—

1. Can hear sounds of any kind.
2. Can hear words spoken.
3. Can understand words spoken.
4. Can see objects.
5. Can see printed or written words.
6. Can understand printed or written words.
7. Can speak voluntarily.
8. Can repeat words.
9. Can read aloud.
10. Can write voluntarily.
11. Can write from dictation.
12. Can copy.

These questions cover defects of graphic, as well as of spoken language, so-called *alexia* and *agraphia*, as well as aphasia, in the narrow sense. Passing tests 2, 3, 5, 6, and failure to pass 7, 8, 9, 10, 11, 12, would indicate cortical motor aphasia. Passing tests 2, 3, 5, 6, 10, 11, 12, and failure to pass 7, 8, 9, would indicate subcortical motor aphasia. Passing tests 5, 7, 10, and failure to pass 2, 3, 6, 8, 9, 11, 12, would indicate cortical auditory aphasia. Passing 2, 3, 7, 8, and failure to pass 5, 6, 9, 10, 11, 12, would indicate cortical visual aphasia. And so on.

CHAPTER XVI

MENTAL TESTING

EXPERIMENTAL psychologists have, in recent times, devoted great attention to the subject of mental testing, both from a theoretical and from a practical point of view. Theoretically, the main purpose of investigation has been to determine whether there is such a thing as *general intelligence*, and, if so, to define its nature, and trace its development. Practically mental tests find diagnostic, educational, and vocational application, as we shall see presently. In this field experimental psychology takes on a somewhat novel aspect. Introspection is virtually abandoned, attention being concentrated solely on the results produced by the subject under the test conditions or in the test situation. Technique is simplified by the minimizing of the use of apparatus and the stereotyping of procedure. Careful and accurate statistical treatment of data assumes an importance it possesses in no other field of experimental psychology.

In the ordinary man's scheme of the social universe one of the fundamental axioms is that some men are more "intelligent" than others. When pressed to say what he means by "intelligent," he will answer by some such phrase as "able to see through things," or "able to learn things." The opinion of the ordinary man is shared by the teacher. School records seem to show most unmistakably that children differ in "intelligence," and that this difference shows itself in practically all branches of school work, so that the difference in "intelligence" seems to amount to a difference in general capacity, or all-round ability, as far as school work is concerned. Here, then, the first problem for experimental investigation presents itself. That is to determine whether the opinion of the ordinary man, and of the school teacher, that individuals differ from one another in respect of a general character, which

may be called "general intelligence" or "general capacity," has any foundation in fact. The emphasis is really on the word "general." We know that men differ in special capacities, as, for example, in acuity of vision or hearing, in pitch discrimination, in immediate memory, in fertility of imagination, and so on. So much our work in experimental psychology up to the present has clearly shown. But when it is implied that there is some general or central factor which enters into practically all special capacities, and in which individuals differ from one another, that is obviously an implied assertion that demands special evidence.

The Problem of the General Factor.—The solution of the problem of the real existence of a general capacity depends, in the first place, upon our being able to test special capacities, and in the second place, on our possessing some means of determining whether the performances in these tests indicate, or not, the presence of a general factor, exerting an influence, though in varying degrees, upon all. It has been claimed that we do have the necessary tests, and that in the correlation coefficient we have a means of determining the extent to which one and the same central factor influences the performance in different tests. This is not the place for a theoretical discussion of these contentions, and it must be said that there are several points at which somewhat acute controversy has developed. We are here concerned merely with the experimental procedure that has been adopted.

The employment of the correlation coefficient in a relatively simple case may be illustrated by some investigations carried out early in the present century by Aikins and Thorndike. They asked the question whether there is any general ability, that may be described as general speed of association. Then they tested individuals for speed of different kinds of association. If, in such an experiment, correspondence, as indicated by the coefficient of correlation, is shown between the speed in one kind of association and the speed in another kind, that may be taken as evidence in favour of the existence of a general ability of the kind sought. If no significant degree of correspondence shows itself—as was actually the case in the particular investigation cited—then we may argue that there is no evidence of the existence of any such general capacity as "quickness of association."

An earlier investigation than that of Aikins and Thorndike,

on somewhat similar lines, but involving what may be called the typical procedure where the problem of general intelligence is being studied, was that of Wissler. Wissler obtained the college marks in various subjects of 200 students, and gave these students some simple mental tests. He then calculated the correlation between the marks obtained in one college subject and those obtained in the others, between the results of one test and the results of the others, and finally between the results of the tests and the marks in the college subjects. The argument would be that if there is correspondence between the marks in different college subjects, this is evidence for the existence of a factor or factors influencing efficiency in all the subjects showing correspondence of marks, and to the degree indicated by the degree of correspondence shown. Similarly, if there is correspondence in the results of the different tests, this means that a common factor is influencing these results. And, finally, if there is correspondence between the college marks and the test results, the presumption is that the same general factor is manifesting itself in both cases. As it happened, Wissler got considerable correspondence indicated between the marks in the various subjects, but relatively slight correspondence in the other cases.

Thus, to determine whether a general factor is influencing the results of different tests we calculate the correlation coefficient between these tests. To determine whether this general factor is what we call "general intelligence" we obtain some measure or measures of "general intelligence"—in Wissler's investigation the college marks—and calculate the correlation coefficient between this and the test results. If there is perfect correspondence or correlation, the correlation coefficient calculated by means of the formula given in the Introduction will be + 1. If there is perfect inverse correlation it will be − 1. Hence the correlation coefficient will be some value between + 1 and − 1. The degree of correspondence, direct or inverse as the case may be, will be indicated by the value of the coefficient. Generally speaking, a value below ·4 is not very significant, though the significance of any value depends on circumstances. The procedure we have described holds good whether what we call "general intelligence" is a simple factor or a complex of factors. That is, after all, the main practical point. If we seek to define the nature of "general intelligence" the calculation of correlation is still the method

we employ, though the precise procedure is beyond the scope of the present discussion, and the results obtained are more difficult of interpretation. At this point, in fact, controversies have developed into which there is no need to enter at present.

For experimental psychology the most important outcome of the work on the general factor has been the devising of tests suitable for the measurement of general mental capacity, whatever may be its ultimate nature, and for the study of its development in the child, and its variations among children and adults alike. In the early days of the investigation we have been discussing, the tests employed were, in the main, simple sensory or motor tests, with tests of attention and of memory. As the work proceeded, tests involving higher mental processes—such tests as those employed in the study of the thought processes, as already described—were added. At the present time, tests of the latter type are almost exclusively employed when we desire to test intelligence for practical purposes.

The reason for this development is admirably shown in a series of investigations by Burt. These began with an investigation in Oxford. The subjects were school children between the ages of 12½ and 13½. Twelve tests were employed, ranging from simple sensory and motor tests to tests of voluntary attention and the span of apprehension. An independent estimate of the intelligence of the subjects was obtained from school marks, the opinion of the teachers, and the opinion of the headmasters of the schools from which they were drawn. The kind of correlations obtained is indicated by the following table (the correlation is with the independent intelligence estimate in each case) :—

Test.	Correlation.	Test.	Correlation.
Spatial threshold .	·13	Card-dealing . .	·44
Weight discrimination .	—·13	Card-sorting . .	·52
Pitch discrimination .	·40	Alphabet finding .	·61
Comparison of lengths	·29	Learning . . .	·57
Tapping	·47	Mirror drawing .	·67
Span of Apprehension	·76	Irregular dotting .	·80

Thus, simple sensory and motor tests have evidently little correlation with general intelligence, but tests involving the higher mental processes show, as we should expect, considerable

correlation. Burt had this in mind in his second experiment, which was carried out in Liverpool, in which he added to the tests previously given several tests involving even more definitely the higher mental levels, such as the analogies test, the syllogism test, the Ebbinghaus completion test, the picture reconstruction test, and several others. In the Liverpool investigation the highest correlation (·72) was given with the reconstruction of pictures test.

The theoretical aspects of intelligence testing were soon overshadowed by its practical aspects, and the most important outcome of all this work on the general factor was, as we have already indicated, the providing of a great number of valuable tests of which a practical use could be made in assessing an individual's mentality. To the consideration of the chief developments in this direction we must now address ourselves. Isolated tests of the type employed in the investigations we have been discussing may be employed for the practical purpose of determining an individual's mental level. For such tests to be really serviceable, four main essentials must be kept in mind :—

1. The tests must be easy of application.
2. They must require little or no apparatus.
3. They must yield results which can be measured in quantitative terms.
4. They must, as far as possible, measure innate ability, so that no individual may be placed at an advantage owing to better education and better opportunities.

In place of a " battery " of individual tests, however, it has become customary in individual testing to employ graded scales, the " battery " of single tests being reserved, as we shall see presently, for group-testing.

Graded Mental Scales.—Graded scales of tests are specially adapted for that particular kind of practical purpose which may be termed " diagnostic." The best-known graded scale is that devised by Binet and Simon, which has served as the basis of nearly all recent work in this field. In devising the Scale that bears their names, Binet and Simon had two ends in view: (1) to find the grade of mentality of any individual child; and (2) to diagnose mental deficiency in particular. The latter was really the original aim of the tests, but the aims of the investigators widened as the work went on.

The Binet-Simon Graded Scale—or more briefly the Binet Scale—consists of a series of tests arranged in order of difficulty.

The first scale devised—the 1905 series—consisted of 30 simple tests arranged in this manner. The mentality of the subject was estimated by the number of tests he could pass. When we speak of the Binet Scale, however, we rarely refer to the 1905 series, but to the later series of 1908 and 1911. In the 1908 series most of the tests of 1905 were retained, but 33 new tests were added. The notion of a graded scale was retained, but modified in such a way that the tests were arranged in year groups corresponding to what purported to be normal mental age from 3 to 13, the norms being established by an examination of 200 French children, drawn mainly from the poorer classes. This series was subjected to considerable criticism from several points of view. In particular it was claimed that many of the tests were wrongly placed. In order to remedy this defect, which was, in part, acknowledged by Binet himself, the 1911 series—the Binet Scale as we now know it—came into existence.

The Binet Scale of 1911 did not differ very materially from that of 1908. A few tests depending too much on scholastic attainments or environmental conditions were dropped, some transposing of tests to more suitable age-groups took place, and the number of tests in each age-group was fixed at five, the requisite number of tests for this purpose being added. Otherwise the series of tests presented no new features. A more satisfactory method of reckoning a subject's mental age, however, was proposed. The mental age was obtained from the age at which the subject passed all the tests, with the addition of one year for every five tests passed beyond.

The Binet Scale was tried out by investigators in various countries. As a result several modifications were suggested. The chief revisions of the tests have been those of Goddard, Kuhlmann, Meumann, Terman, and Burt. The most important of these revisions is probably that due to Terman, and known as the "Stanford Revision." As a result of testing 1000 children, Terman came to the conclusion that for American children the Binet Scale was not very satisfactory. He found that the Scale was too easy at the lower end and too difficult at the top, that many of the tests were still wrongly placed, even in the 1911 series, that several of the tests were of relatively small diagnostic value, and that valuable types of test were omitted. Accordingly, the Stanford Revision represents very considerable modification of the Binet Scale. There are

90 tests arranged in 12 age-groups, for ages 3, 4, 5, 6, 7, 8, 9, 10, 12, 14, 16, 18, with six tests in each group and several alternative tests. A method of recording mentality, originally suggested by Stern, is adopted. This is by means of what is called the Intelligence Quotient (I.Q.), which is the ratio of the mental age in months to the chronological age in months. From age 3 to age 10 the subject is credited with 2 months for each test passed, and thereafter with 4 months.

Terman maintains that the ratio of the mental age of a child to the chronological age under normal conditions remains constant, so that the I.Q. of a child tested at any age remains a permanent characteristic of that child. On the whole, experimental evidence would seem to bear this out. The child whose mental age corresponds exactly with his chronological age has an I.Q. of 100. The child of normal or average intelligence may be said to be the child with an I.Q. between 90 and 110. The distribution of I.Q.'s is shown by the following table :—

I.Q.	Per Cent.	Mentality.
Above 140	1	Genius
120-140	5	Very superior
110-120	14	Superior
90-110	60	Normal or average
80-90	14	Dull
70-80	5	Border-line—feeble-minded
Below 70	1	Feeble-minded or defective

The latest,[1] best, and most comprehensive revision of the Binet Scale for English children is the London Revision by Burt. This is based more closely on the Binet Scale of 1911 than the Stanford Revision. With the co-operation of Simon, Burt has translated the tests into terms and situations suitable for London children, and in the process has considerably re-adjusted the placing of the tests. His attitude, however, to the Binet Scale differs from that of what we may call the American school. In place of regarding the scale as substantially sound, and merely requiring adjustment here and there, Burt is inclined to look on it merely as a temporary expedient, and holds that what is necessary is not a remodelling of the old scale, but an entirely new series of tests. As a result of his investigations he concluded that with normal children the Binet tests,

[1] There is a later revision by Terman and Merrill (1937).

as tests of intelligence, are only moderately satisfactory, though more trustworthy with defectives. Taken singly, the diagnostic value of the tests varies enormously, and some of them are of little value. For older and brighter children, such as candidates for scholarships, he is inclined to abandon the use of the Binet tests almost entirely in favour of tests of reasoning or of the higher mental processes, arranged in some graded series.[1]

One unsatisfactory feature of the Binet Scale is the "pass or fail" system of marking. This may involve, on the one hand, the sacrifice of valuable data, and, on the other hand, injustice to the subject. To avoid this defect "Point Scales" have been devised, in which by the assigning of points to each test, partial credits are rendered possible. The best-known of such Point Scales is that due to Yerkes, Bridges, and Hardwick. This scale consists of twenty tests, most of which are those of the Binet Scale, and the mental examination is by means of the scale as a whole. To each test a definite number of points is assigned. The number of points credited to each subject is obtained by adding all the points scored in individual tests, the maximum being 100. Once norms have been established, we can get the mental standing of any individual by comparing his score with the average score for his age, and we can also obtain a rating corresponding to Terman's I.Q.

Another recent attempt to avoid this defect of the Binet Scale is the Herring Revision, which is, in reality, not so much a revision as a new series of tests. The Herring Revision combines the main features of the Binet Scale with those of the Yerkes-Bridges Point Scale. In addition, it presents characteristic features of its own. This scale consists of 38 tests, each test consisting usually of a number of different parts, for each of which points are assigned. The characteristic feature of the scale, however, is that mental age can be determined by the use of fewer than the 38 tests. There are five groups of tests. Group A comprises tests 1 to 4, Group B tests 1 to 13, Group C tests 1 to 22, Group D tests 1 to 31, and Group E tests 1 to 38. We can obtain a mental rating from any of the groups.

We must always begin with test 1, and then pass on to tests

[1] Burt has shown that success in the Binet tests depends to a very great extent on scholastic attainments—to the extent of about 50 per cent. indeed, and this has been confirmed by other investigators and indirectly by evidence from other sources, as, for example, from an investigation of the intelligence of canal-boat children in which it was found that the I.Q. declined with increasing age owing to want of schooling.

2, 3, and 4. If desired the examination may stop there, and an approximate mental rating may be obtained. To get this we add the scores obtained for the four tests, and from an appended table read off the corresponding mental age in months. If a more careful examination is possible, or is desired, Group B is administered. This means that we give the additional tests to complete Group B. But the score in Group A is taken as a reliable index of the subject's ability to perform some of the tests of Group B, and, according to the score in Group A, some of the tests, therefore, are to be credited in full without being given. The others in Group B are given, and the score in Group B is the sum of the scores in Group A, of the points for the tests in Group B not given, and of the scores in the additional tests given. As before the score is translated into mental age by means of an appended table. Precisely the same procedure is followed with Groups C, D, and E.

There are other graded series of tests in addition to those modelled on the Binet Scale. A single type of test may be employed and the individual tests graded in difficulty. The most interesting series of this kind is probably Burt's series of reasoning tests, already alluded to. But it is obvious that any good intelligence test may be used as the basis for such a series.

Performance Tests.[1]—Nearly all the tests hitherto described rely very largely on the use of language, and are, therefore unsuitable for use with children having certain special defects, such as speech defect or deafness, or for use with illiterates. Special non-linguistic tests have, for this reason, been devised, which employ the manipulation of concrete objects. These are known as "performance tests." The following are some of the chief tests of this kind, which have been employed on anything like an extensive scale:—

1. The Form-board. This type of test has been extensively used by Healy and others to diagnose mental defect. Many different forms of the test are in existence. Essentially it consists of a number of wooden blocks of various shapes, square, triangle, etc., each to be fitted into a hole of similar shape. The time taken by the subject, and the procedure followed, are recorded. In some cases, the placing of the blocks is aided by the fact that the blocks not only fit into the proper holes, but also complete a picture. This involves a combination of the Form-board with the next type of performance test.

[1] Tests for pre-school children such as those devised by Gesell and by Stutsman belong characteristically to this type.

2. Picture Completion. Various forms of this have been employed. A picture may be dissected into a number of rectangular sections, and the subject required to build up the picture. Or the subject may simply be required to fit into each of a series of pictures the appropriate parts, all the parts cut out being similar in shape and size.

3. The Maze. This scarcely requires description. The subject is required to trace the path through a maze without crossing any lines, and the time taken, together with the course followed, is recorded.

4. The Cube Test. The subject has to tap four cubes in the order in which they are tapped by the experimenter.

Several other performance tests of a similar type have been devised. In some instances individual performance tests have been arranged so as to give a graded series of tests. Two of these ought to be specially mentioned. The one is Kohs' Block Design Scale, the other the Porteus Maze Scale.

Kohs' Block Design Scale consists of a series of designs of increasing difficulty which must be constructed by means of coloured blocks. Similarly, the Porteus Maze Scale consists of a series of mazes of increasing difficulty. It is a very useful test with feeble-minded and defective children, but less suitable for normals, except those with some language handicap or defect. Another scale of performance tests is the Pintner-Paterson Performance Scale. This differs from the Kohs' Scale and the Porteus Scale in that a number of different tests are employed—fifteen in all. The tests can be arranged so as to give a mental rating in various ways, but those who have used the scale prefer a rating based upon median performance, as given in tables drawn up by the authors. The Army Performance Scale is drawn up in much the same way as the Pintner-Paterson, and comprises, in part, the same tests.[1]

Group Testing.—The individual test is employed when any particular diagnosis is required, but where a large number of individuals have to be tested the time consumed becomes a rather serious consideration. To obviate this difficulty and economize time as much as possible, the Group Test has been devised. By means of the Group Test a large number of individuals may be tested simultaneously. A great impetus was given to group testing by the American Army Tests. These tests, which were given to nearly two million men during the Great War, were drawn up by a committee of leading American

[1] See for a recent Performance Scale, Drever and Collins, *Performance Tests of Intelligence*, Edinburgh, 1928.

psychologists. Their object was on the one hand to select fit men of sufficient ability to be placed in posts of responsibility, and on the other hand to eliminate men of too inferior mentality to be worth training. The tests could be administered in about fifty minutes, and groups as large as 500 could be tested at the same time.

Two sets of group tests were drawn up by the American Army psychologists, the first for subjects who could read and write English—the Army Alpha Tests—the second for illiterates and foreigners—the Army Beta Tests. The first consisted of eight tests—following directions, arithmetical problems, practical judgment, synonyms and antonyms, disarranged sentences, number series, analogies, and information. This may be taken as typical of the usual Group Test. The tests were printed in a booklet, one type of test on each page, and were so arranged that the minimum of writing was required. A time limit was assigned for each page, which was such that even the most intelligent could hardly hope to complete all the tests, but the least intelligent could do some. In order to prevent coaching, several different and equivalent forms of the Army Alpha were prepared.

Other notable series of tests of the same type as the Army Alpha are the Otis, the Simplex, the Haggerty, the National Intelligence. In all these, tests of the same kind are grouped together on one page. This has several disadvantages, not the least of which from a practical point of view is the necessity of timing each page separately to get a fair rating of an individual's mental standing. This disadvantage is obviated in Thomson's Northumberland Group Tests, and Thurstone's Psychological Examination, by arranging the various items in cycles. The result is that only one timing is necessary, that of the test as a whole, and yet every subject is enabled to do tests of all the different types.

The time limit in Group Tests is an almost unavoidable disadvantage. It penalizes the slow thinker, who is not necessarily the individual of low mentality. For this reason group testing can only be regarded as of the nature of a "first aid." Wherever accurate mental rating is necessary—and the results of the Group Test may indicate this—individual testing must be added. In particular, unexpectedly low ratings by group testing must be confirmed by individual testing.

Temperament and Character Tests.—To be of real service,

intelligence tests must be supplemented by tests of character and temperament, a sphere of study which can only be said to be still in its initial stages.

The investigations into character and temperament have taken four directions. In the first instance, attempts have been made to analyse the personality into its ultimate elements, and then to assess the individual for each trait. These schedules of human traits, while helpful in providing a clear survey of the ground to be covered, are open to the criticism that the traits tabulated are not really essential traits of personality, but are complexes of habits, neatness, tact, etc.

Secondly, attempts have been made to classify individuals into different categories, according to the type of temperament possessed. We find in this group James' differentiation into the explosive type of person and the obstructed type; or we may point to the more recent schema of glandular types.

Thirdly, rating scales have been devised, by means of which individuals can be rated in order of merit for some particular trait. Or each individual can be rated separately from a key previously drawn up. The classic example of this latter is the Army Rating Scale devised by Scott, which was intended to pick out those who would make efficient officers. The first step in drawing up a rating scale is to decide on the traits which are essential, and in this instance five qualities were suggested :—

1. Physical qualities (physique, neatness, voice, bearing).
2. Intelligence (ease in learning, ability to issue clear orders, to estimate new situations, etc.).
3. Leadership (initiative, force, tact, self-reliance, etc.).
4. Personal qualities (industry, loyalty, readiness to take responsibility for his own acts, ability to co-operate, etc.).
5. General value to the service (professional knowledge, skill and experience, success as instructor, etc.).

The rating scale, therefore, makes sure that the judgment will not be based on minor qualities nor on minor defects, but that the essential qualifications will be taken into account. Once the qualities are agreed upon, what is the next step? How is the scale made? A list is drawn up by a brother officer, of about a dozen officers of his own rank, men with whom he has served, or with whom he is well acquainted. In the list are included officers whose qualifications are poor or mediocre, as well as those who are highly efficient. Then the first trait,

physical qualities, is taken, and the names are considered from that point of view only. Every characteristic is disregarded except the way in which the officer impresses his men by his physique, by his bearing, by his neatness, etc. That officer is selected who surpasses all others in this qualification, and his name is entered on the line marked highest under physical qualities. Then the one is selected who most conspicuously lacks these qualities and his name is entered on the line marked lowest. Then the officer is selected who seems about half-way between the two previously selected, and who represents about the general average in physical qualities. Then the officer who is half-way between the middle and the highest is selected, and his name entered on the line marked high. Finally, the officer who ranks half-way between the middle and the lowest is chosen and his name entered on the line marked low. Each grade is allotted so many points, thus :—

Physical qualities,	Highest	. . . .	15
,, ,,	High	. . . .	12
,, ,,	Middle	. . . .	9
,, ,,	Low	. . . .	6
,, ,,	Lowest	. . . .	3

In the same way scales are made for each of the other four sections, Leadership, Personal Qualities, Intelligence, and General value to the service.

The scale is used in this way. The subordinate is rated for physical qualities first of all. He is considered as to how he impresses his men by his physique, bearing, voice, energy, and endurance. He is then compared with each of the five officers and ranked with the one he most nearly equals. If he falls in quality between two officers in the scale, he is given a number of points accordingly. Traits three and five, are evaluated according to which officer the subordinate will most equal after equivalent experience. The total rating for a subordinate is the sum of the ratings given him in the five separate qualities, the average being about sixty points.

This is a typical rating scale, and exhibits the principle on which such scales are drawn up when persons are rated according to a key. The other method is merely to rate the persons in order of merit without reference to a key, such as arranging a class of school children for one particular subject or personal trait.

Rating scales have multiplied indefinitely and are used extensively in the educational and industrial world, more in America, perhaps, than in this country. It is useful for teachers to draw up rating scales for their pupils, not merely to assess their traits, but in order to diagnose, if possible, wherein a defect may lie, and to suggest lines of improvement. It will be evident that a rating scale offers more valuable data than any judgment based upon purely undirected lines. The greater the number of judges, too, who assess the individuals, the better and more objective the result. The main disadvantage of rating scales is that judges are often biassed by their general attitude towards a given individual. Unconsciously their attitude affects their rating, and because of one conspicuous defect, a person may be ranked low in all the assessments, or because of an outstanding social trait or " halo," he may be overestimated.

Self-rating scales have been suggested in which the individual is asked to assess his own character, but the results have not been too reliable. In one investigation the individual's estimate of himself was compared with an estimate of him by others. It was found that the individual was a very bad judge of himself, and the students who carried out the test, 110 of them, were found to overrate themselves, and underrate their fellows. Further, there was a clear tendency to speak well of themselves in those virtues considered of greater importance by them, and to rate themselves less highly in traits considered less vital. This correlation between the relative importance of traits and the amount of each trait a subject rates himself as possessing, may well be considered a self-defence mechanism, whereby a person tends to think well of himself in what he judges important, and evens up by under-rating himself in less significant terms. As the investigator expresses it, " Common sense shows that all of us would be readier to admit poor memory, or poor handwriting, than poor judgment, or inferior trustworthiness." From this tendency, Allport suggests establishing a *conceit* index by a qualitative determination of the extent to which an individual's self-rating varies in either direction, from the average rating by a number of other judges.

The fourth line of approach has been the devising of actual tests. They are mainly American in origin, and of these we shall briefly indicate three.

The Ethical Discrimination Test, devised by Kohs, attempts to measure moral judgment by noting how often the child or

adult singles out moral reasons in preference to reasons of a more personal nature. It is not unlike an intelligence test, but with moral situations substituted, and it lends itself to group investigation. There are six tests in all, a Social Relations Test, a Moral Judgment Test, a Proverbs Test, a Definition of Moral Terms Test, an Offence Evaluation Test (a series of virtues and offences which have to be evaluated by marking a cross in the appropriate column, the columns being headed: Praise, Nothing, Scold, Jail, Prison, Kill), and a Moral Problems Test.

Each test is scored on a percentage basis, and from the average score the moral age can be ascertained, and the *moral* Intelligence Quotient. This test is one of the most promising, although it undoubtedly tests intelligence as well as moral judgment.

The Pressey "Cross-out" Test is of a different type, and has been drawn up to study the complex emotional life of the individual. Lists of mixed words are presented to the examinee, who is required to cancel out all which have unpleasant feeling-tone associated, etc. The test gives considerable insight into the emotional make-up of the individual, and may indicate the presence of complexes.

Its outstanding disadvantage is that there is no objective control, and the examiner has to rely completely on the good-will and honesty of the subject.

The June-Downey Will-Temperament Test is an investigation into the volitional make-up of the individual and tests such traits as adaptability, self-confidence, power of restraint, patience in detailed work, and other qualities.

The test, as a whole, is based on handwriting under different conditions, normal, slow, rapid, disguised, etc. The tests, twelve in all, are given in a specific order. Each is rated on a score of ten, and the final result is drawn in the form of a graph which represents the will-profile of the individual.[1] The test is a most interesting one, but seems to place too much weight on the personality of the examiner.[2]

Vocational Guidance and Vocational Selection.—One of the most fruitful fields for the application of mental testing is the vocational. Two problems in this field must be clearly distin-

[1] For a fuller account, see June-Downey's *The Will-Temperament and Its Testing.*

[2] The phenomenon of perseveration (see p. 233) has recently been suggested as a temperament test.

guished from the outset to avoid confusion. There is, on the one hand, the problem of vocational guidance, and on the other, the question of vocational selection. The former is concerned with the choice of an occupation for an individual, while the latter is concerned with the choice of an individual for an occupation.

Vocational guidance is the more difficult problem of the two, and, as already indicated, involves advising the individual as to the nature of the vocation for which he is best fitted. Vocational guidance, in time, will gradually absorb vocational selection, for if vocational guidance is effective, only suitable workers will apply for vacant posts. This ideal, however, is far distant, and consequently, vocational guidance and vocational selection will continue for some time yet to exist side by side.

In assessing vocational requirements, three methods have been employed :—

1. *The Method of Enquiry* is useful, either verbally in the course of conversation, or by means of a questionnaire. For example, Lipmann has drawn up a questionnaire of eighty-six questions regarding various abilities, each question requiring the reply "yes" or "no." "Does the position of —— require the following abilities : (1) perception of inadequately illuminated objects ; (2) perception of slight noises ; (3) perception, recognition, and discrimination of faint odours, etc." Other questions refer to other traits.

A different type of questionnaire has been devised by Piorkowski in Berlin. He asks if an ability is (*a*) essential ; (*b*) merely desirable ; (*c*) of no importance for the exercise of a trade, and so on.

2. The second, the *Method of Observation*, is particularly useful to supplement any other data. There are certain factors which can only be tested in this way, and the suggestion has been made that the industrial psychologist be initiated into the work in question, and by observation of his own difficulties, become more proficient in his analysis.

3. The third, the *Method of Experiment*, is the essential and most reliable method, and this we shall discuss more fully when we consider the more specific problem of vocational selection.

In addition to the determination of specific vocational talents, the examinee's physical condition, intelligence, temperament, and educational attainments must also be considered, for undoubtedly all posts require varying qualifications of each of these. It is as unprofitable to place a man of low intelligence

on a high grade job as to give a man of high intelligence a job incompatible with his mentality. Similarly, temperamental misfits must be guarded against. A gay, spirited person is often quite unsuited for dull, routine work, which a more placid individual would find congenial.[1]

Vocational Selection.—The problem of vocational selection has become an urgent one because of the large labour turnover so prevalent in many factories. This labour turnover—i.e., the ratio of the number engaged in a year to the number employed at any one time—is in certain workshops enormous, and these misfits who are the source of the trouble, mean considerable loss to the firm.

The labour turnover has made employers anxious to adopt some method of selecting employees which will give satisfaction. As a result, vocational selection has sprung up, and at present, vocational tests are in existence for a number of trades—telephone operators, shorthand typists, dressmakers, various branches of engineering, and many others.

Claparède divides vocational tests into two kinds :—

1. Psychological tests, based on the "structure and working of the mind." They include intelligence tests, tests of educational attainments, and tests of temperament.

2. Occupational tests, based on the "structure and working of the occupation." The methods employed in occupational tests have evolved gradually into four types. They may be described as sample tests, analogous tests, analytic tests, and empirical tests.

(1) *Sample Tests.*—Standardized samples of the actual work may be given to test the examinee, such as is usually done in typewriting or in shorthand. The obvious disadvantage of this method is that it can only be employed for testing purposes after the individual has undergone a certain amount of training. In consequence, if the examinee is not proficient, and has no aptitude for the vocation, it will involve loss to all concerned.

(2) *Analogous Tests.*—The method of drawing up analogous tests is somewhat similar to the first method above. But instead of investigating the actual operations involved in the work, a test is so devised that the examinee has to adjust himself to it in the same manner as if it were the work proper, and reactions are elicited similar to those required in the right situation.

[1] The National Institute of Industrial Psychology has carried out in London an extensive investigation into vocational guidance. See Earle, *Choosing a Career*, London, 1932.

An excellent illustration is that of Münsterberg's test for electric tramwaymen or the more recent test of Sachs for the same purpose, constructed at the Hamburg Psychological Laboratory.

"The subject stands before an endless black band about 13 cm. broad, a length of about 130 cm. being visible, which travels towards him at a constant rate. Single holes and pairs of holes appear in this band at various distances from one another, the former indicating pedestrians and the latter vehicles. By means of a series of lamps, any single hole or pair of holes can be illuminated at different distances from the subject. The danger from a "vehicle" is always greater than that from a "pedestrian," and the danger from either is increased in proportion to its nearness to the subject. According to the degree of danger, one of three responses is required: the ringing of a bell with the foot, the moving of a lever with the left hand, and the "putting on a brake" with the right hand. The conditions in which these responses are respectively required are defined.

"On either side of the moving band, and at some distance from it, are two boxes, each containing a single hole and a pair of holes, either of which can be illuminated independently of the other. These, when illuminated, represent sudden emergencies of pedestrians or vehicles from either side of the track, and the reactions then required are the same as those required for corresponding stimuli on the moving band. Finally, a coloured light, situated some distance from the apparatus, is switched on and off intermittently, and the subject is required to count the number of times this occurs. All stimuli and reactions are recorded on an electrically-driven smoked drum." [1]

A practice series is first tried, of about twelve minutes' duration, after which the subject is given the test proper. The score is based upon the number of inaccurate responses, which is compared with the norms obtained by previous testing of good, poor, and indifferent drivers.

(3) *Analytic Tests.*—Analytic tests are constructed by analysing the occupation into its elementary functions and giving a series of tests bearing on these factors. For example, during the War, candidates for the Royal Air Force were tested by means of psychological tests. They were tested for ability to detect and localize sounds, for ability to recover the balance quickly,

[1] *Report of the Industrial Fatigue Research Board*, No. 12, General Series, No. 4, by B. Muscio.

to see stereoscopically, to see in dim illumination, and to react promptly to sudden noises. The special qualifications necessary for success were analysed to begin with, and then tests were devised to examine each qualification separately.

It may be asked, how it is known that the tests used correspond to the elementary operations required in the occupation. Link, in his *Employment Psychology*, gives an excellent example of an investigator devising and trying out tests. In this case the work in question was that of inspecting shells before they were loaded, and removing those with defects. After becoming familiarized with the work, an analysis of the entire operation caused Link to state that five qualifications were required: good eyesight, keen visual discrimination in order to recognize those shells which were defective, quick reaction necessary to extract the faulty shell and toss it into the appropriate box, accuracy of movement essential for picking the right shell, steadiness of attention so that faulty shells would not be overlooked.

The problem now was to devise tests which would correspond closely with these factors. Link chose eight in all.

1. A simple eyesight test.

2. A card-sorting test. The subject was given a pack of 49 cards, upon the face of each one of which from 7 to 12 letters were distributed promiscuously. Twenty of the cards contained the letter "O." The subject was asked to sort these cards into two piles, those which had "O" on them, and those which had not. The time required was taken and the number of errors made recorded.

3. A tapping test. The subject had to give as many taps as possible in a minute. A Veeder counter was used.

4. A cancellation test. A large page containing the numbers from 0 to 9 repeated over and over in irregular order was handed to the subject, who was asked to cross out as many sevens as possible in the allotted time.

5. An easy directions test.

6. A number-checking test. This consisted of a series of numbers, each containing six digits; the subject was requested to put a mark beside each number containing a 1 and a 7.

7. An accuracy test. A brass plate with circular holes forming a series in size, and a metal rod, were the apparatus. The task was to insert the metal rod in each of the holes in turn

without allowing the rod to come into contact with the circumference of the circle. Fifteen trials were given, and the average of the last ten taken. The score of each trial was the hole in the series at which contact was made with the circumference. The whole experiment was timed with a metronome, and each contact was electrically recorded.

8. A steadiness test. This is a somewhat similar test to above. The apparatus in this case consisted of two metal bars, the distance between them at one end being of a fair width, but which gradually diminished as their other ends were approached, although the two bars never actually met. A metal rod was to be drawn between those two bars, without coming into contact with either. Contacts again were electrically recorded, and, as in test 7, the last ten trials out of a total of fifteen were taken to represent the score.

The tests were then tried out, on 52 girls, among others, who were engaged on the work of inspecting shells, and the results computed. The next step was to obtain the ranking of the girls, as shown by their daily work, in order to evaluate the tests, for it would not necessarily follow that those who had done well in the tests were necessarily the best workers. The average hourly production of each girl for a period of four weeks was taken as standard and this was compared with the performance of each girl in each of the tests. This was done to obtain the degree of correspondence or the degree of correlation. The following results were obtained :—

Card sorting	·56
Tapping	·14
Cancellation	·63
Easy directions	·14
Number group checking	·72
Accuracy	·38
Steadiness	·24

The three tests of card-sorting, cancellation and number group checking were the only ones with correlation coefficients above ·5. These, therefore, were adopted as satisfactory tests, and the others were rejected. These three became the vocational tests for that particular job, and will be given to all applicants before they are engaged for the work. This procedure depicts one of the most general methods followed in devising vocational tests.

(4) *Empirical Tests.*—In this fourth method, a number of tests are chosen at random, and those are accepted as good tests which yield large correlation coefficients with efficiency in the occupation. There is no connection sought for between the test and the elementary ability. For example, it was found that the completion test showed a very marked correlation (·63) with engineering ability. Claparède was of the opinion that it is impossible to place complete reliance on such results and that the fact that a given test does correlate highly with a given industry is no guarantee of its trustworthiness. The result may be purely a chance one.

The serious criticism which has been levelled against all occupational tests is that they assess individuals by tests which have been successfully performed by workers experienced in the vocation in question. What is necessary to free occupational tests from this grave criticism is the proof that the passing of the test is not favoured by the period spent in apprenticeship and training.

To a certain extent, vocational selection is solved by the provision of Vestibule Schools which are attached to certain factories. The Vestibule School is a preliminary training school in which to observe the qualities of the new applicant, and it also gives the applicant a certain amount of choice in his future work. The Vestibule School resembles a laboratory in which the examinee is observed under controlled conditions and where he can be allocated to that task in the factory for which he is best suited.

Note.—Projection Tests and Projective Techniques.

A great impetus was given to methods of assessing "personality" during the Second World War. Among the new techniques widely applied was the type generally known as "projective." This is a technique which involves the free expression by the individual himself of his own thoughts and feelings, while, as it were, "projecting" himself into a situation presented to him. Binet's method of studying the thought processes of his two daughters (p. 238) is an early illustration of this kind of experiment, the "Masselon Method" (p. 237) is another, the "ink-blots" experiment (p. 237) a third. A more elaborate development of the last is the Rorschach test. The most interesting, however, and probably the most important of these tests, from a practical as well as a psychological point of view, is the "Thematic Apperception Test." In this a series of untitled pictures are presented, one at a time, to the subject, and he is asked to write the story, using his own imagination, for which each might serve as an illustration.

The precise assessment of the results of these tests is still in the experimental stage. The principle on which it is based is the discovery of "pointers" for personality phenomena and characteristics. On the validity and reliability of such "pointers" the whole assessment must necessarily depend.

APPENDIX A

THE PSYCHO-ORGANIC SYSTEM

THE animal body is built up of living cells of varying form and function. All living cells present certain common characteristics. In general, the main portion of the cell consists of a gelatinous substance—protoplasm—enclosed in a fine membrane. A portion of the protoplasm within the cell is specially modified and enclosed in another delicate membrane, to form what is called the *nucleus*, which is, as it were, the centre of the cell's life. Within the nucleus one or more particles may be seen under the microscope as highly refracting bodies. These are *nucleoli*. Living cells reproduce themselves by subdivision, the process starting in the nucleus.

The living organism, so long as it is living, is continuously active. Its activities comprise the various functions performed by the living cells of which it is built, and these functions fall into two groups :—

1. Vital Functions—the functions involved in nutrition, growth, reproduction ; and 2. Adaptive Functions—the functions involved in the response of the organism to stimulation from without. In the complex organisms at the top of the animal scale, including the human being, the cells subserving each function usually form great organs or organized systems. Though vital and adaptive functions are not really separable in the concrete, yet in a discussion of psychology we are concerned in the main with adaptive functions, and may, therefore, confine our attention to these.

The organized system of cells by means of which the adaptive functions of an organism are carried out may be designated the *psycho-organic system*. Since adaptation consists in response to factors in the environment, the function performed by the psycho-organic system as a whole has necessarily two aspects, which might be described briefly by the abstract terms *sensibility* and *motility*. In a primitive organism both aspects may appear in the function of one type of cell. In the highly organized animals, however, the psycho-organic system consists of three groups of cells, one group specialized for the reception of stimuli—sensibility—a second group specialized for the making of the necessary

response—motility—and a third group specialized for the associating and co-ordinating of the functioning of these two groups. We speak, therefore, of the psycho-organic system of the human being as comprising a group of *receptor* cells (the sense organs), a group of *effector* cells (muscles and glands), and a group of *connecting* cells (the nervous system).

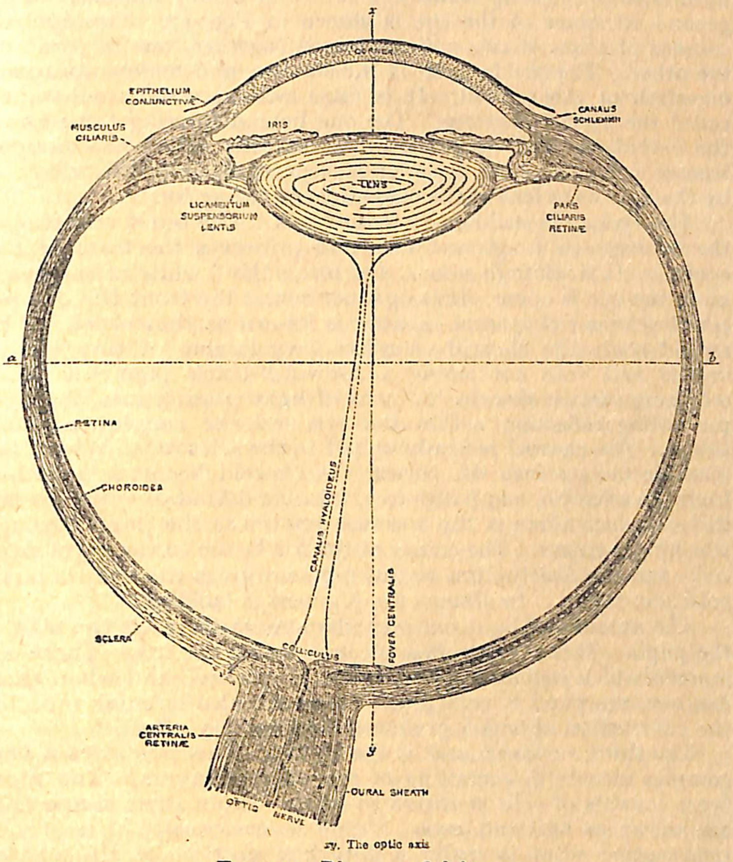
The Receptors

The receptor cells are cells specialized to receive various kinds of stimuli. By their receiving stimuli we mean that the stimuli produce definite changes in the cells. The nature of the changes produced is not always clear, but it is such as to produce, in turn, a nervous excitation in the neurones of the connecting group of cells. These receptor cells constitute the essential parts of what we call the *sense organs*, the other parts of the sense organs—where other parts exist—being accessory, and having the function of making the reception of the stimulus more efficient, and the response of the organism in consequence more effective. The receptors are called exteroceptors, interoceptors, or proprioceptors, according as they are situated on the external surface of the body, the internal surface—that is, the surface of the alimentary canal, etc.—or within the tissues of the body.

Since the receptor cell has to transform a physical stimulus into a nervous impulse (by way, probably, of a chemical process in most cases), the structure of the receptor cells varies with the kind of physical stimulus to which they are adapted to respond—what is known as the *adequate* stimulus. The accessory parts of the sense organs similarly vary with the kind of stimulus which the essential parts are adapted to receive. We may now consider the sense organs in turn.

1. The Eye.—The eye consists of an essential part—the sensitive surface or *retina*—and two accessory parts—the *dioptric system* and the *muscular system*. The real meaning of the dioptric and muscular systems is best understood when we regard the organ of vision from the point of view of its development. All the senses may be looked upon as developments of a primitive sense of touch. The sensitive surface of the eye is sensitive to the touch of the ethereal vibrations we call rays of light. The first stage in the evolution of vision is represented by pigmented spots on the external surface of the organism, specially sensitive to light. Possessed of such primitive eyes, the organism could distinguish between light and darkness. Resting, say, on the bottom of the sea, it could react to the shadow of an approaching enemy. Such an eye, however, could not distinguish the form of an approaching object. In order that form may be distinguished, some arrangement is necessary to cast an image of an

object on the sensitive surface. This is the function performed by the dioptric system. With a fixed dioptric system a clear image will only be thrown on the sensitive cells when the object is at a certain distance and in a certain direction. The function of the accessory muscular system is, on the one hand, to make the



xy. The optic axis

FIG. 17.—Diagram of right eye.

dioptric system effective for objects in different directions, and, on the other hand, to make it effective for objects at different distances. In the evolution of the eye we have first the sensitive pigmented spot, then the fixed dioptric system, and lastly the movable dioptric system.

Essentially, the eye is a camera. The retina represents the sensitive plate behind. But, whereas in a camera focussing is carried out by altering the distance between the lens—the dioptric system—and the plate, in the eye this alteration is impossible, and focussing is carried out by altering the curvature of the lens by means of the suspensory ligament and ciliary muscles. The general structure of the eye is shown in Fig. 17. The eyeball consists of parts of two spheres joined together, one in front of the other. The one in front is the smaller, and makes up about one-sixth of the eyeball. It is filled with a watery substance called the *aqueous humour*. The one behind forming the rest of the eyeball is filled with a transparent jelly called the *vitreous humour*. The aqueous humour is separated from the vitreous by the bi-convex lens of the eye—the *crystalline lens*.

The eyeball is enclosed in three coats. The outer covering—the sclerotic—is tough and firm and preserves the form of the eyeball. It is white in colour, and forms the " white of the eye " when the eye is open. It is opaque, but at the front the opaque coat becomes transparent in what is known as the cornea. The second coat—the choroid—consists very largely of tiny blood-vessels and cells containing a brownish-black pigment. This colouring matter absorbs the rays of light passing into the eye, preventing reflection within the eye and the consequent confusion. The choroid is firmly united to the sclerotic. Where the sclerotic merges into the cornea the choroid becomes detached from the sclerotic, and hangs free, forming a kind of curtain—the iris—in which there is the aperture known as the pupil through which light enters. The colour of the iris is due to the pigmented cells, and the distribution of this pigment gives the eye its characteristic colour. In albinos the pigment is lacking.

The amount of light entering the eye varies with the size of the pupil. This is controlled by muscles in the iris. There are muscles which radiate like the spokes of a wheel, and when these contract the pupil is enlarged. There are also circular muscles, the contraction of which produces the contrary effect.

The third, or inner, coat is the retina. This possesses a very complex structure, consisting of ten distinct layers. The ninth layer consists of cells sensitive to light. From their shape they are known as *rods* and *cones*. Other layers consist of neurones, representing what is really a detached portion of the central nervous system, of which we shall learn more presently.

In the centre of the retina is the area known as the *macula lutea* or *yellow spot*. In the centre of this is a depression known as the *fovea centralis*, which is the point of clearest vision. The coloration which tinges the yellow spot is strongest at its periphery, weakens towards the centre, and probably disappears entirely in

the fovea itself. The existence of the yellow spot can be demonstrated by looking through a solution of chrome alum at a brightly lighted surface. In the blue-green solution a rose-coloured spot will be seen, which corresponds to the yellow spot. It can also be very beautifully demonstrated with violet or purple gelatine sheets (see Sanford, *Experimental Psychology*, p. 105). In the fovea, cones alone are found. The total number of cones in the eye has been estimated at three millions, and of these no less than seven thousand are in the fovea. The *blind spot*, where the optic nerve enters the eye, is situated towards the inner or nasal side of the fovea.

At the junction of the choroid and the iris are found the ciliary muscles, which are attached to the suspensory ligament of the lens, and, as we have seen, serve to modify its curvature. When the ciliary muscles contract, the biconvex lens, as it were, bulges out, and the focal length is diminished. Conversely, when the muscles relax, it is flattened. Hence the muscles are sometimes known as the " accommodation muscles." The crystalline lens is kept in place by the membrane known as the suspensory ligament. In the ordinary resting condition of the eye this ligament is tense.

The rays of light which strike the eye are partly cut off by the iris and by the sclerotic. Only those rays which strike the pupil are allowed to enter. These rays pass, in turn, through the cornea, the aqueous humour, the lens, the vitreous humour, and reach the retina. There they pass through the several layers until they strike the rods and cones, where, apparently, a chemical change is produced, giving rise to a nervous impulse. This is transmitted through the several layers till it reaches the optic nerve.

The extrinsic muscles of the eye, that is, those attached outside the eyeball to the sclerotic, are in pairs, and have as their function the movement of the eyeball in the socket. There are six such muscles—three pairs. The superior rectus moves the eyeball upwards, the inferior rectus downwards. The external rectus turns it outwards, the internal rectus inwards. Movement in intermediate directions is secured by the inferior and superior oblique muscles.

2. **The Ear.**—The receptors for sound stimuli are hair cells in the inner ear. Each cell ends in a brush of hairs projecting into the fluid which fills the inner ear. These hair cells constitute the essential part of the organ of hearing; all the rest we may regard as accessory. As in the case of vision we may look on hearing as developed out of a primitive sense of touch, the receptors being specialized so as to respond to the touch of air vibrations The response becomes more delicate and discriminating by the

immersion of the hair processes attached to the sensitive cells in a fluid to which the air vibrations are, in the first instance, communicated.

The organ of hearing, as it exists in the human being, consists of three parts—the outer, the middle, and the inner ear. The outer ear begins with the auricle or visible ear. A tube—the external meatus—runs from the outside air inwards. At its inner end is the ear-drum or tympanum. On the other side of this membrane lies the middle ear, bounded by the tympanum on one side, and a bony wall containing two apertures fitted with membranes on the opposite side. These apertures are called, from their shape, the *fenestra ovalis*, or oval window, and the *fenestra rotunda*, or round window. A narrow tube—the Eustachian tube—also leads from the middle ear to the throat at the back of the mouth. Across the middle ear from the tympanum to the fenestra ovalis extends a chain of tiny bones called, respectively, the *malleus*, or hammer; the *incus*, or anvil; and the *stapes*, or stirrup.

The hammer is attached at its handle end to the centre of the tympanic membrane. At the middle it is held by a tendon. The head articulates with the anvil. The anvil articulates in the same way with the stirrup. To the latter a small muscle, the *stapedius*, is attached, and the base of the stirrup fits into the fenestra ovalis. When air waves pass through the external meatus and throw into vibration the tympanum, the vibrations are transmitted by means of the three bones to the membrane of the fenestra ovalis, which, in turn, is made to vibrate.

The internal ear lies securely imbedded in the bone of the skull, and has a somewhat complicated structure. It consists essentially of a sac containing fluid—the *endolymph*—which rests in a second fluid—the *perilymph*. The complete structure is called the membranous labyrinth, and the bony cavity in which it is found the bony labyrinth. The labyrinth consists of two main parts—the semi-circular canals, constituting the end-organs of the static sense, and the cochlea, the end-organ of hearing.

The cochlea somewhat resembles the shell of a snail with two-and-a-half whorls. It is divided lengthwise by partitions into three tubes. One of these—the *scala vestibuli*—starts from the fenestra ovalis. Through it vibrations are carried from the base to the apex of the cochlea. At the apex they pass into the second tube—the *scala tympani*—in which they are carried down from the apex to the base, and which terminates at the fenestra rotunda. Both tubes are filled with perilymph. A third tube, filled with endolymph, lies between them to the outside. It is separated from the scala tympani by the *basilar membrane*, and is itself known as the *scala media*. On the basilar membrane rests a

series of rods, with hair cells, known as the *organ of Corti*. These cells are, as we have seen, the receptors for sound stimuli. They are so arranged as to be set in vibration by the vibration of the surrounding fluid, the result being the starting of a nervous impulse in the auditory nerve. Above the organ of Corti lies the *tectorial membrane*. The basilar membrane varies in breadth as it passes from base to apex of the cochlea. If we compare its fibres to the strings of a musical instrument like the harp, the short fibres at the base correspond to the short strings of the harp, and the long fibres at the apex to the long strings of that instrument. (See Fig. 18 and Chapter II.)

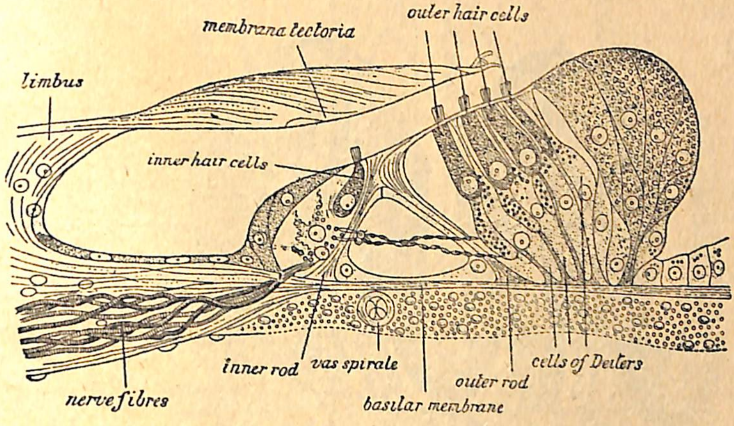


FIG. 18.—Section through the organ of Corti. (Lickley after Retzius.)

In hearing sounds then, the air waves are collected by the outer ear and transmitted by the external meatus to the tympanum, which is set in vibration. The vibration is communicated to the chain of bones, and thence to the fenestra ovalis, and the perilymph within the inner ear. In the perilymph the waves pass up the scala vestibuli and down the scala tympani to the fenestra rotunda, whence they pass out. The waves in the perilymph cause a vibration of the membranous walls of the scala media, which is communicated to the endolymph within. These vibrations in the endolymph stimulate the hair cells of the organ of Corti, producing a nervous impulse, which passes by means of the auditory nerve to the nervous centres.

3. The Organ of Taste.—The tongue is the chief organ of taste, but sensations of taste may also be experienced in the soft palate and neighbourhood. The tongue is covered with a mucous

membrane in which are to be seen small prominences, or papillæ, which take three forms. The *filiform* papillæ are the most numerous. The *fungiform* papillæ, which are easily discriminated by their bright-red appearance, are found interspersed among the former. Thirdly, the *circumvallate* papillæ are found near the root of the tongue, about twelve in number, arranged in the form of a V, with the apex pointing backwards. The circumvallate papillæ derive their name from the fact that each is surrounded

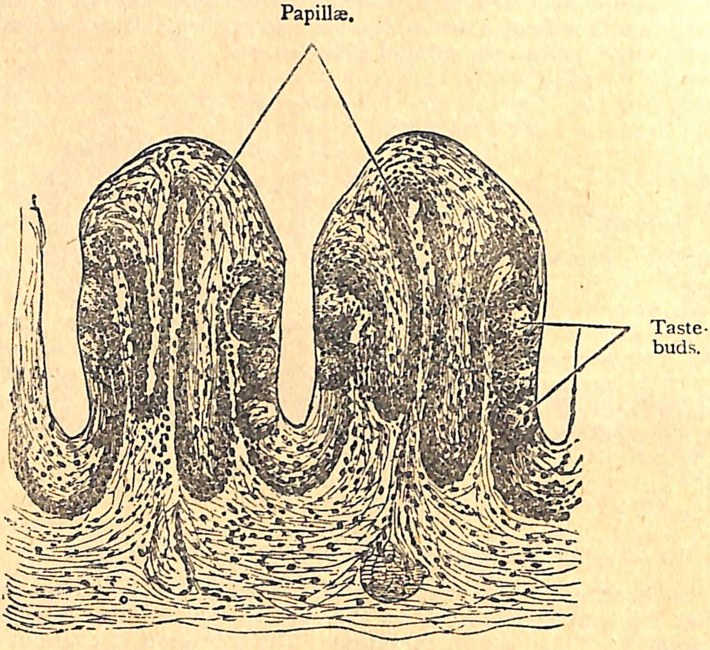


Fig. 19.—Taste papillæ.

by a deep trench and wall. The two latter varieties of papillæ give us our sensations of taste. In them we find the receptive organs for taste arranged in the form of taste buds. The taste buds are oval in appearance, and are composed of three layers of cells. The outer cells are mainly protecting cells, and are arranged round the inner cells like the staves of a barrel. The second layer of cells seems just to support the inner cells, which are the true taste cells. These are hair cells, and form a group in the centre of each taste bud having a part projecting through the free surface of the taste bud—known as the gustatory, or taste pore—

in the form of a tuft of fine threads, or hairlets, which receive the stimulus. The stimuli must always be in the form of a solution, and to secure this we find near the taste organs innumerable small glands whose secretions assist the process. Insoluble substances have no taste but may give an experience of cold, or pressure, or some other sensation on the tongue. The nerve fibres are very complicated, and seem to connect up with the different taste buds from three different sources. These are

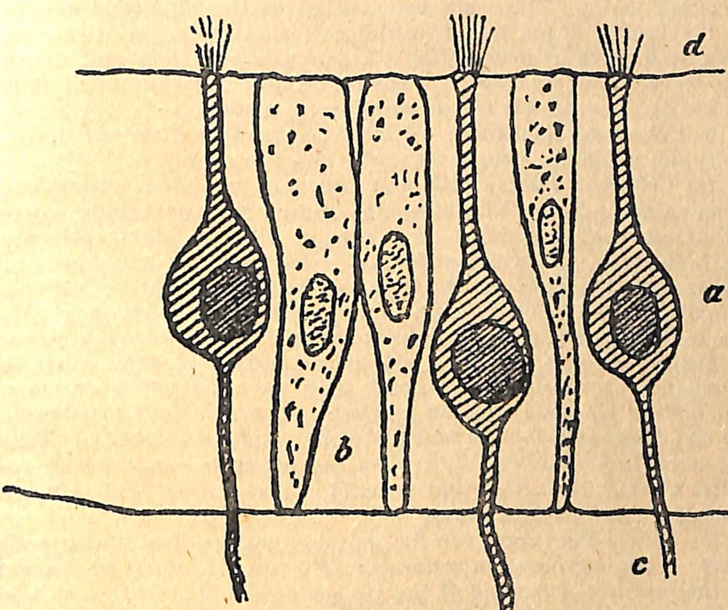


FIG. 20.—Olfactory cells.
a. Hair cell with *d* projecting hairs.
b. Supporting cells.
c. Filament of Olfactory nerve.

conveyed as nervous impulses to the taste region in the cerebral cortex. The tongue is also a muscular body and assists the act of tasting by causing movement of the fluid.

4. The Organ of Smell.—The organ of smell is the delicate mucous membrane which lines the two nasal cavities. There are two kinds of cells, olfactory cells, and supporting cells. The supporting cells are columnar in shape; the olfactory cells are bipolar, one end extending upwards in the form of a delicate

filament ending in a small knob from which five to eight fine hairs project upwards. The other end extends downwards, and is connected with a fibre of the olfactory nerve.

The stimuli which act on these cells are very minute particles which may travel from a great distance, and which are brought into the nasal cavity in the process of respiration. As they pass through, some of these particles stimulate the olfactory cells, causing chemical changes which initiate the impulses in the olfactory nerve. These are transmitted to the olfactory centre in the brain. Kant has defined smell as taste at a distance, because it gives us information of the quality of food and drink by way of the air we breathe. Hence, because of its function, it is placed at the entrance to the respiratory system.

5. Cutaneous Sensations.—From the skin four different sensations are obtained: cold, heat, pain, and pressure.

(*a*) *Cold and Heat.*—Cold and heat are included under the temperature senses. The adequate stimuli for the temperature senses are heat radiations issuing from objects which directly touch the skin, and which stimulate it because they are lower or higher than the temperature to which the particular locality is adapted. The object may be in the form of a fluid or a gas. The temperature senses are often stimulated from internal sources by organic changes occurring within the body; or they may be stimulated by mechanical stimuli such as an electric current. The bulb of Krause is said to be the receptor for cold; whereas the end organ of Ruffini is said to be the receptor for heat. This lies more deeply embedded, so that the response for warmth requires a longer time than that for cold. The cold spots are more numerous than the heat spots.

(*b*) *Pain.*—Pain spots are the most numerous of all cutaneous spots. Pain is aroused in a number of ways. It may be caused by the pricking or cutting of the tissues of the skin. It can also be aroused by intense heat or cold, or pressure; or pain spots can be stimulated electrically. The nerve fibre loses its sheath after passing into the outer covering or the epidermis of the skin, and splits up into numerous branches. These branches terminate between the cells of the epidermis, and in some cases penetrate into them. They are very numerous in the cornea of the eye, which is strongly susceptible to pain, and are entirely absent in an area on the inside of the cheek, which is immune from pain.

(*c*) *Pressure.*—The corpuscles of Meissner and Pacini, and the nerve endings at the roots of the hairs are or contain receptor cells for pressure or touch. Any object which touches the skin, all mechanical stimulation of the skin, or the touch of a hair serves as a stimulus for pressure. Distinction must be drawn

between hairy and non-hairy regions. The hair itself serves as a pressure stimulation, but if it be shaved off, a pressure spot will be found to the "windward" of each hair. The finger tips, which are particularly sensitive to touch, contain a great number of Meissner's corpuscles. J. B. Watson states that the average number of spots per square cm. is about 25, but they may drop as low as 7 or go as high as 300.

6. The Kinæsthetic Sense.—Kinæsthetic sensations are located in muscle, tendon, and joint. The sense organs concerned are somewhat difficult to investigate, partly because they are so deeply embedded in the tissues, and partly because the sensations themselves are so closely bound up with cutaneous and other sensations that it is difficult to distinguish them with any clearness. The so-called *muscle spindles* are, apparently, receptors in the muscles and tendons. In the joints receptors of the same type as those found in the cutaneous surface have been identified.

7. The Static Sense.—In integrated behaviour kinæsthetic sensations are closely associated with the sensations derived from the semi-circular canals. Two of these canals lie in vertical planes at right angles to one another ; the third lies in the horizontal plane at right angles to the other two. They are filled with endolymph. The hairs of hair cells project into this. Movements of the head cause movements of the endolymph to stimulate the hair cells. The *utricle* and *saccule*, with which the semicircular canals are connected are supposed to supplement the functions of the canals in maintaining the equilibrium.

8. Visceral Sensations.—Sensations are also obtained from the organs of respiration, from the heart, from the organs concerned in digestion, etc. Receptor cells are, therefore, situated in the various internal organs.

The Nervous System

The nervous system constitutes a great connecting system of cells, by means of which the cells that make the response of the organism are associated and co-ordinated with those that receive the stimulus, and the cells of each group with one another. The cells of the nervous system are called *neurones*. The neurone may, therefore, be described as the structural unit of the nervous system. It consists of a cell body (the nerve cell) and one or more processes. Two types of process must be distinguished. One type receives the nervous impulse and transmits it to the cell. These are the *dendrites*. As a rule they leave the cell body as thick stems, which soon break up into a number of fine filaments. The other type is represented for the most part by a long process, which may give off branches at intervals (collaterals), but which remains practically unchanged in diameter until it terminates in

an arborization of fine filaments. Only one such process leaves each cell body. It is called an *axon*, and its function is to conduct the nervous impulse away from the cell body. According to the number of processes leaving the cell body, nerve cells may be classified as *unipolar*, *bipolar*, and *multipolar*. The unipolar cells, however, in the human being, are really bipolar, but the two processes leave the cell body together, and diverge later.

Nerve cells consist of protoplasm, with nucleus and nucleolus. Running through the protoplasm are numerous fine fibrils (neuro-fibrils), which pass into the processes, and which are probably the paths by which nervous impulses are conducted. Within the cell there are also granular masses, which stain readily with aniline dyes. These are called *Nissl granules*, and they apparently constitute the food material for the cell.

Though the structural unit of the nervous system is the neurone, its functional unit is the *sensori-motor arc*. This consists of two or more neurones. One neurone—the sensory or afferent—conducts the impulse from the receptor, or inwards towards the centre, a second—the motor or efferent—conducts the impulse towards the muscle or gland, or outwards from the centre. According to the usually accepted theory, the neurones are not structurally continuous with one another. Their relationship is contiguity, not continuity. The arborization of the axon of one neurone may be round the cell body, or intricately interlaced with the branching of the dendrites of another neurone, but there is always a gap—a break in the continuity of substance. Such a gap where two neurones communicate in this way with one another is called a *synapse*, and the passage of the nervous impulse at a synapse is conceived on the analogy of the passage of the electric spark across a spark gap. This view, however, does not go without challenge. Some maintain that the neuro-fibrils pass from one neurone to another across the gap at the synapse.

The cell bodies of neurones are generally found in aggregations called *ganglia*. The greatest aggregations are in the cerebro-spinal axis formed by the brain and spinal chord. There are, however, ganglia apart from this. Such ganglia are formed by the cell bodies of the sensory neurones connected with the receptor organs. These ganglia belong with the brain and spinal cord to the great *cerebro-spinal system*. In addition, there are ganglia and groups of ganglia in association with the chief internal organs and the glands of the body, constituting what is known as the *autonomic* or *sympathetic system*.

Nerve fibres are formed by the processes of the neurones. The fibre consists of a series of fibrils continuous with the neuro-fibrils of the cell body. A bundle of nerve fibres held together

by connective tissue constitutes a nerve. In the human being there are two kinds of nerve fibre—the *medullated* and the *non-medullated*. Medullated nerve fibres are characteristic of the cerebro-spinal system. They consist of an *axis cylinder*, which is usually the axon of a neurone, but in the case of the peripheral sensory nerves is a dendrite, and a sheath surrounding it, called the medullary sheath, composed of a white fatty substance. The medullary sheath is interrupted at intervals, these interruptions being designated the nodes of Ranvier. Outside the medullary sheath is a thin membrane called the *neurilemma*, which covers the fibre continuously outside the cerebro-spinal axis, with the exception that the terminations of all nerve fibres are without any sheath or membrane. This passes into the covering membrane of the central masses when the fibre enters the cerebro-spinal axis, and is not found within. The medullary sheath is absent in nerve fibres of the autonomic system, which are covered directly by the neurilemma. Because of this sheath the appearance of the two sets of nerve fibres is different, and they are in consequence sometimes spoken of as *white* and *grey* fibres respectively.

When a nerve fibre is cut off from the cell body to which it belongs, it undergoes degeneration. In this process the medullary sheath breaks up into globules or granules of fatty substance, and the structure of the axis cylinder is also broken down, so that ultimately the neurilemma appears to be filled simply with a relatively structureless mass of nucleated protoplasm. Such a degenerated nerve fibre stains intensely with osmic acid, and this fact has been taken advantage of in tracing connections in the central masses of the cerebro-spinal system. The part of the fibre still connected with the cell body does not undergo degeneration, at least as a direct result of the section. If regeneration takes place, it takes the form of growth from the central stump of the cut nerve. Within the cerebro-spinal axis regeneration does not take place, or takes place in a very incomplete way.

The Cerebro-spinal Axis.—The main masses of nervous matter belonging to the cerebro-spinal system are situated within the skull and the spinal canal. These masses are composed of so-called white matter and grey matter, the latter owing its appearance and designation to the presence of large numbers of cell bodies. The cell bodies of all the sensory neurones are, indeed, situated outside the cerebro-spinal axis, but otherwise all the cell bodies of the neurones belonging to the cerebro-spinal system are in the masses occupying the skull and the spinal canal. The chief structures of the cerebro-spinal axis—naming them from below upwards, and from behind forwards—are the following: the *spinal cord*, the *medulla oblongata*, the *pons Varolii*, the

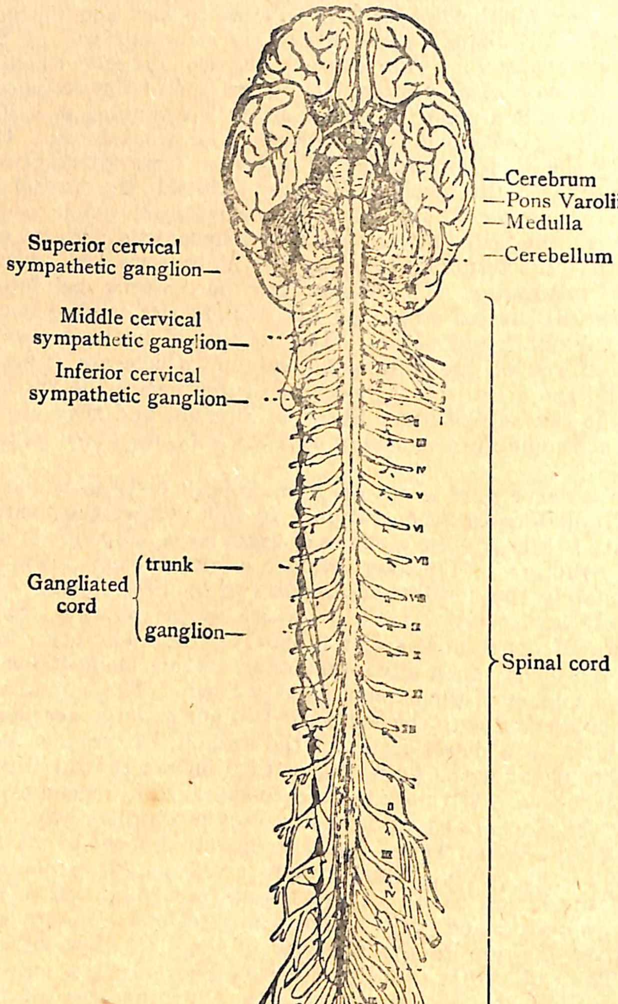


FIG. 21.—The central nervous system showing connexions with the sympathetic.

cerebellum, the *corpora quadrigemina*, the *optic thalami*, the *corpora striata*, and the *cerebrum* (see Fig. 21). All these except the spinal cord are situated within the skull, and therefore form part of what is popularly known as the brain. The medulla, the pons, and the cerebellum form what is called the "hind brain," the corpora quadrigemina, with other neighbouring structures, form the "mid brain," and the others the "fore brain." These together occupy the cavity of the skull, constituting what is popularly designated the "brain." The spinal canal is occupied by the spinal cord. All the structures consist of nerve cells, nerve fibres, and what is generally described as a supporting or connecting substance termed *neuroglia*, the precise function of which is not definitely known.

The spinal cord is an elongated, roughly cylindrical mass of nervous matter, extending about two-thirds of the length of the spinal canal from the junction of the spinal column with the skull downwards. A well-marked groove extends down the front of the cord—the *anterior median fissure*—and a much narrower and shallower grove down the back—the *posterior median fissure*. The substance of the cord is enveloped in three membranous sheaths, the innermost—the *pia mater*—enclosing the cord closely, and being separated from the middle envelope—the *arachnoid* membrane—by a space containing cerebro-spinal fluid, and this membrane, in turn, being separated from the outermost membrane—the *dura mater*—by a very narrow space kept moist by lymph. These membranes are continued over the masses of nervous matter in the skull. The spinal cord is also traversed from end to end by a narrow central canal containing cerebro-spinal fluid. This and the sub-arachnoid space pass at the top into the so-called *ventricles* in the brain, which are similarly filled with cerebro-spinal fluid.

At regular intervals the spinal nerves pass out from both sides of the spinal cord. Each nerve has two roots, an anterior and a posterior. The posterior root is a sensory root, and has on it a ganglion where the cell bodies of its neurones are gathered together; the anterior root is motor. Each spinal nerve, therefore, is composed of both sensory and motor nerve fibres. A transverse section of the cord shows the grey matter arranged in a form roughly resembling the letter H in the centre, and the white matter surrounding it (Fig. 22). This white matter consists of descending and ascending nerve fibres, some of these being the collaterals of the axons of sensory neurones, others the axons of motor neurones. The two sides of the spinal cord are connected together by the transverse bar of the H. The limb on either side is regarded as being formed by two portions, spoken of as the anterior and posterior *horns*. The grey matter

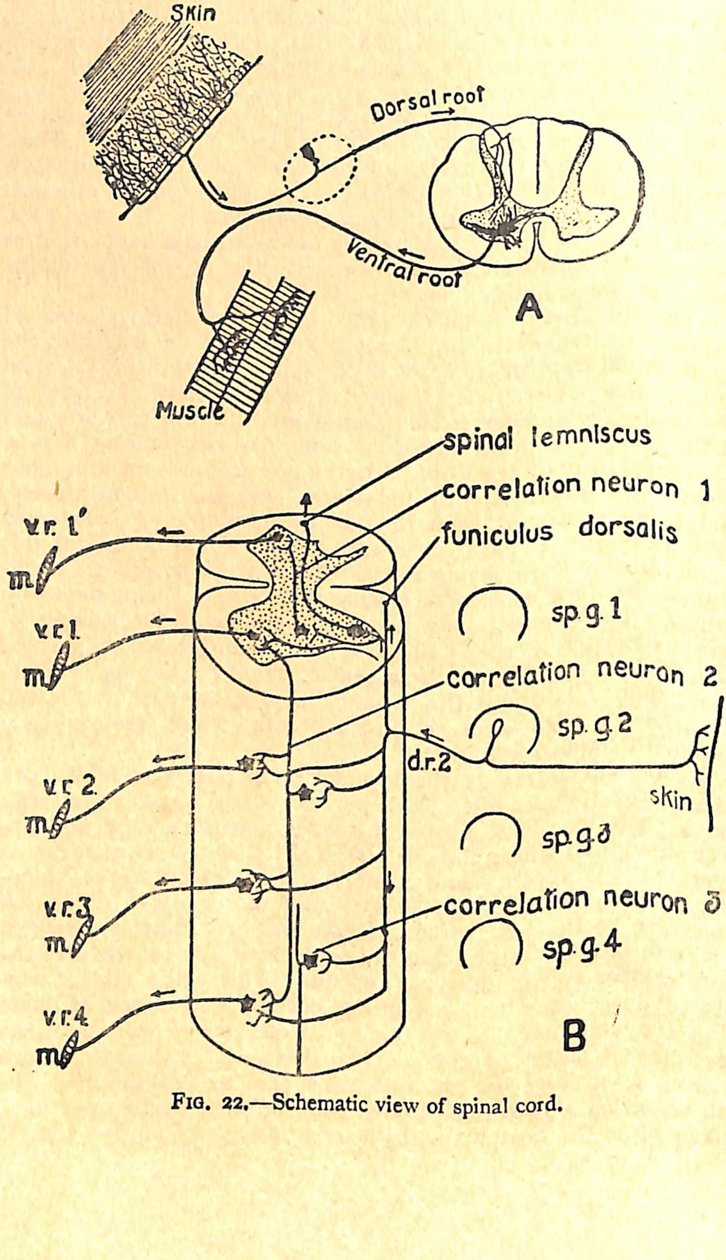


FIG. 22.—Schematic view of spinal cord.

of the anterior horn contains, for the most part, the cell bodies of motor neurones, and is the point of origin of the anterior motor roots of the spinal nerves. On the other hand, the cell bodies in the grey matter of the posterior horn are largely those of connecting neurones. These neurones have usually short axons, and these arborize round the cell bodies of motor neurones in the anterior horn, either of the same or the opposite side.

The "hind brain" is composed, as we have seen, of the medulla oblongata, the pons Varolii, and the cerebellum, the medulla and the pons below, the cerebellum above, with the cavity of the *fourth ventricle* between. The medulla is continuous with the spinal cord. The regular arrangement of the grey matter in the centre and the white matter external to it, characteristic of the spinal cord, begins to be broken up in the medulla. This is due mainly to the fact that great bundles—or "tracts"—of fibres, both sensory and motor, begin to cross over from one side of the spinal cord to the other at this level. This is known as the "decussation of the pyramids." It leads in the pons to a somewhat irregular distribution of white matter and grey matter, and in the cerebellum, as well as higher up in the cerebrum, the grey matter has largely passed to the external surface, with the white matter internal. The cerebellum lies in the back and below in the skull cavity. It is connected by *crura* or *peduncles* to the medulla, the pons, and the "mid brain." Internally, the nervous matter presents a foliated appearance owing to the fact that the surface is incised by transverse fissures, while the grey matter is arranged on the surface, with the central portion consisting largely of white matter. The whole cerebellum is also divided into three lobes. The cerebellar grey matter contains cell bodies of a characteristic form, designated *Purkinje's cells*. These are large, flask-shaped, multipolar cells, with a great number of highly branched dendrites, and a long axon passing into the central white matter.

The "mid brain" is little more than a stem connecting the "fore brain" and the "hind brain." Its upper part consists of the four corpora quadrigemina, the rest being the *crura cerebri* or peduncles of the brain proper. The internal structure shows important masses of grey matter irregularly distributed, and white matter continuing the "tracts" of the medulla and pons.

The "fore brain" is, in the human being, by far the largest and most important part of the cerebro-spinal system. Its main structures are the optic thalami, the corpora striata, and the cerebrum. The great development of the cerebrum in the adult human being has caused it to fold over the other structures, so that the relations of the various parts are not easily seen in any diagram. The accompanying figure (Fig. 23), however, of the

"brain" of a human embryo of three months makes these relations clear.

The cerebrum is a double organ consisting of two hemispheres, a right and a left, separated from one another by a deep fissure,

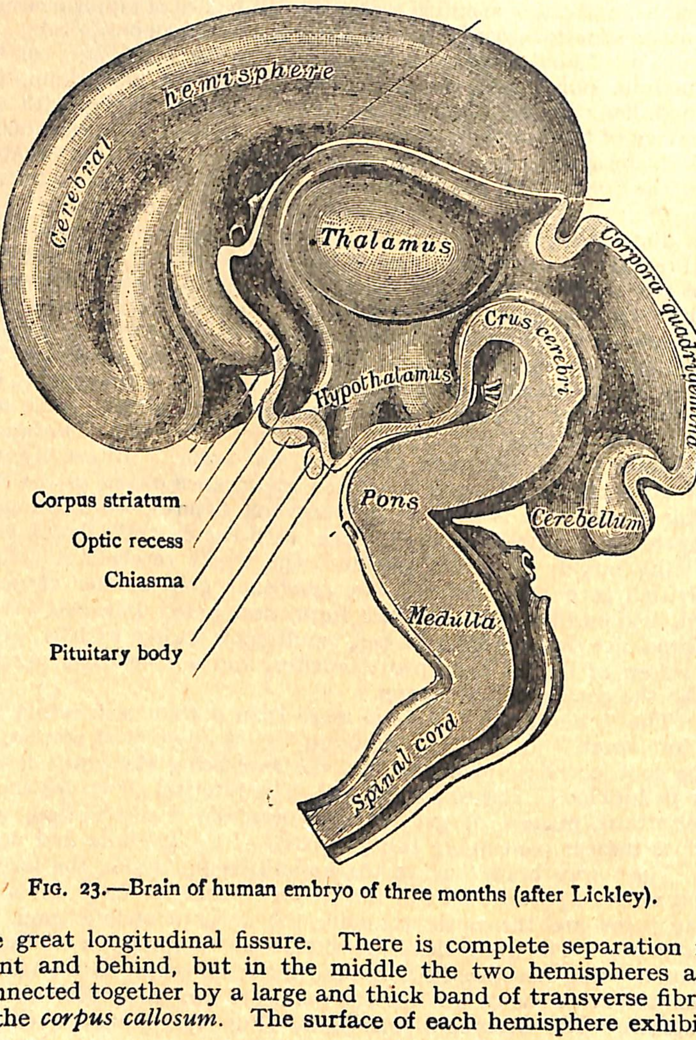


FIG. 23.—Brain of human embryo of three months (after Lickley).

the great longitudinal fissure. There is complete separation in front and behind, but in the middle the two hemispheres are connected together by a large and thick band of transverse fibres —the *corpus callosum*. The surface of each hemisphere exhibits

a series of folds or convolutions, separated by fissures varying in length and depth. While the general pattern of the convolutions remains the same, the detailed pattern differs in different individuals. The folding of the surface or *cortex* has the effect of greatly increasing the superficial area, without correspondingly increasing the bulk of the cerebrum. The convolutions and fissures have no functional significance, but are made use of in the descriptive account of the cerebral cortex.

For descriptive purposes the cortex is divided into lobes. The inter-lobar fissures are the fissure of Sylvius, the fissure of Rolando or central fissure, the parieto-occipital fissure, and the

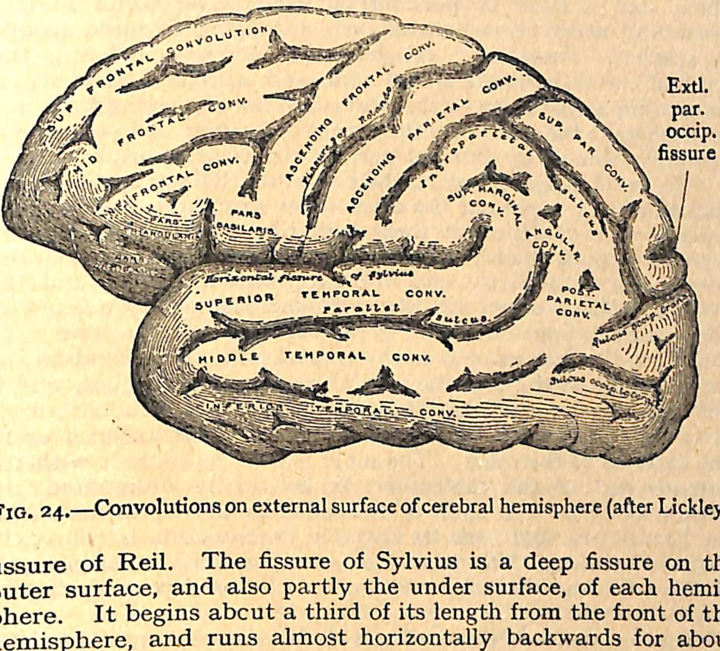


FIG. 24.—Convolutions on external surface of cerebral hemisphere (after Lickley).

fissure of Reil. The fissure of Sylvius is a deep fissure on the outer surface, and also partly the under surface, of each hemisphere. It begins abcut a third of its length from the front of the hemisphere, and runs almost horizontally backwards for about 3 inches. The fissure of Rolando, or central fissure, begins slightly behind the middle of the upper margin, and runs downwards and forwards almost to the Sylvian fissure. The parieto-occipital fissure lies mostly on the medial surface, but a small portion shows itself also on the external surface. It lies backwards from the fissure of Rolando about three-fifths of the distance to the back termination of the hemisphere. The fissure of Reil is a circular fissure round the insular lobe or island of Reil.

This lobe is not visible on the external surface of the hemisphere, but may be seen by drawing apart the sides of the Sylvian fissure. These fissures divide the hemisphere into five lobes, the frontal in front of the fissure of Rolando, the parietal between the fissure of Rolando and the parieto-occipital fissure, the occipital behind the parieto-occipital fissure, the temporal below the Sylvian fissure, and the insular, or island of Reil, as already described.

As we have already seen, the internal structure of the cerebrum shows the grey matter on the external surface, and the white matter in the centre. In the cortex five layers can be distinguished. These are: a superficial layer of fibres, a layer of large pyramidal cells, a layer of small granular cells, an inner layer of fibres, and a layer of polymorphic cells. The white matter consists of nerve fibres—medullated—belonging to three groups or systems. These are: (1) *projection* fibres, connecting the cerebral cortex with the spinal cord, and with the other structures in the skull cavity; (2) *commissural* fibres, passing from one hemisphere to the other as in the corpus callosum; and (3) *association* fibres, linking up different parts of the same hemisphere.

The basal ganglia, that is, the two optic thalami and the two corpora striata, represent the other main structures of the "fore brain." The thalami at their posterior ends overhang the superior corpora quadrigemina. This end has three well-marked projections, the external and internal *geniculate bodies*, and the *pulvinar*. The thalami are joined to one another by a band of grey matter. Four important groups of fibres emerge from each thalamus, the first passing to the frontal lobe, the second to the occipital lobe, a third to the insular and temporal lobes, and a fourth to the parietal lobe. Each of the corpora striata consists of two parts joined to one another only at their anterior ends, one external to the other. The inner is in close contact with the anterior end of the thalamus. It is usually designated the *caudate nucleus*. The outer is embedded in the white matter of the hemisphere, and from its shape in cross-section is called the *lenticular nucleus*. The connections of the corpora striata are chiefly with the thalami, relatively few fibres passing to the cerebral cortex.

The Functions of Different Parts of of the Cerebro-spinal Axis.—The nervous system has often been compared to a telephone system with private exchanges, district exchanges, and trunk lines. It provides for simple direct connections between receptor and appropriate effector, as well as for the co-ordination in all degrees of complexity of both receptors and effectors. The precise connections provided for at any particular point in any of the structures constituting the cerebro-spinal axis have presented a problem to the physiologist since the time when the different functions

of the posterior and anterior roots of the spinal nerves were determined independently by Bell and by Majendie; and patient and laborious research has enabled the physiologist in some slight measure to solve the problem. It has been claimed that the phrenologists, and notably Gall, contributed very materially to our knowledge of the localization of functions in the brain some years earlier. But, giving Gall every credit as a great anatomist, we must still come to the conclusion that his localization of brain functions was haphazard in the extreme, and founded on little real scientific evidence.

The methods of investigation which have led to our present knowledge of the functions of different parts of the cerebro-spinal axis may be classified under three heads, as (1) comparative, including embryological; (2) clinical and pathological; (3) physiological and histological. By correlating the presence and development of particular functions with the development, either racially or individually, of different parts of the nervous system, some localization, though usually not in great detail, is possible. Again, by correlating abnormal behaviour or functioning with pathological conditions in definite localities in the nervous centres, further light is thrown on the localization of functions. Lastly, by physiological methods of three kinds, more detailed knowledge has been accumulating in recent years. In the first place, the results of electrical stimulation of different parts, mainly in the cerebral cortex, have been carefully observed. In the second place, parts of the centres have been destroyed or extirpated, and the results on an animal's behaviour recorded. In the third place, taking advantage of the phenomena of nerve degeneration which have already been described, physiologists have traced the course of the fibres affected by the destruction of definite groups of cells.

The spinal cord is the centre for simple reflex actions and relatively simple co-ordinations. It is also a conducting path to the higher centres. The axons of the sensory nerves, when they enter the cord, send branches downwards, and collaterals from these branches arborize round cells in the posterior horn at different levels, the axons of which, in turn, arborize round motor cells. An intermediate neurone is thus interposed in the sensori-motor arc. A few of the sensory collaterals pass directly to the cells of motor neurones, and in some cases more than one intermediate neurone may be interposed between sensory and motor neurones. The main stems of the sensory axons run upwards towards the medulla and arborize round cells there, the axons from which pass to the opposite side of the body at the decussation of the pyramids, and on to the basal ganglia. The axons of motor neurones similarly run downwards from the decussation of the

pyramids and from above. In the medulla there are also important centres controlling respiratory and vaso-motor changse.

The main functions of the cerebellum appear to be, on the one hand, the co-ordination of the muscle system of the body both for the maintenance of attitude and for the execution of highly skilled movements, and, on the other hand, the control of the mechanism for maintaining balance. There are important connections with the semi-circular canals and with the visual apparatus. The main functions of the ganglia at the base of the brain are co-ordinating functions for the reflex and instinctive acts connected with the special senses. They might also be said, therefore, to represent high intermediate centres for the special senses. This is especially true of the thalamus, which has also recently been shown to be an important emotional centre.

The cerebrum has long been held to be the main seat of the higher psychical processes, and the centre for spontaneous movement. It represents really two levels. The higher of these might be said to be the level of thought proper ; the lower the level of sense-perception and imagery. As a matter of fact, certain areas of the cerebral cortex have been definitely identified, either on pathological or on experimental evidence, with certain functions, sensory or motor, but the identification of areas with thought proper is still largely hypothetical.

As a result, then, of physiological investigation, confirmed by evidence from pathological conditions, it is possible to mark off in the cerebral cortex with a fair degree of definiteness and accuracy certain areas as associated with certain functions. Thus the motor area and the various sensory areas can be taken as determined. When these areas are marked off, a considerable portion of the cortex remains, to which no motor or sensory functions can be assigned. These remaining areas are called " association " areas.

The *motor area* or *zone* has been more definitely and accurately delimited than any other area. It is situated immediately in front of the fissure of Rolando, occupying most of what is called the pre-central convolution, and extending slightly into the frontal convolutions adjoining. Within this zone regions can also be marked off according to the parts of the muscular system of the body with which they are associated. Thus, at the lower end of the motor zone are situated the centres for movements of the head, eyes, etc. (see Fig. 25). It should be observed that stimulation of the motor zone causes muscular contractions on the other side of the body, the fibres crossing over in the medulla. There are also fibres connecting with the motor zone in the other hemisphere.

The *sensory areas*, so far as they have been determined, are

situated in various parts of the cortex. The area for kinæsthetic and cutaneous sensations is just behind the fissure of Rolando, mainly in the post-central convolution. The area for visual sensations is situated in the occipital lobe—in the *cuneus*, or wedge formed by the parieto-occipital fissure and an equally well-marked fissure on the medial surface, the calcarine. The actual sensory area is relatively restricted, but a considerable area round about is visuo-physic—that is, concerned with visual imagery. The middle third of the convolution immediately below the fissure of Sylvius—the superior temporal convolution—is the centre for auditory sensations, and most of the rest of that convolution is the auditory-psychic area. Taste and smell are

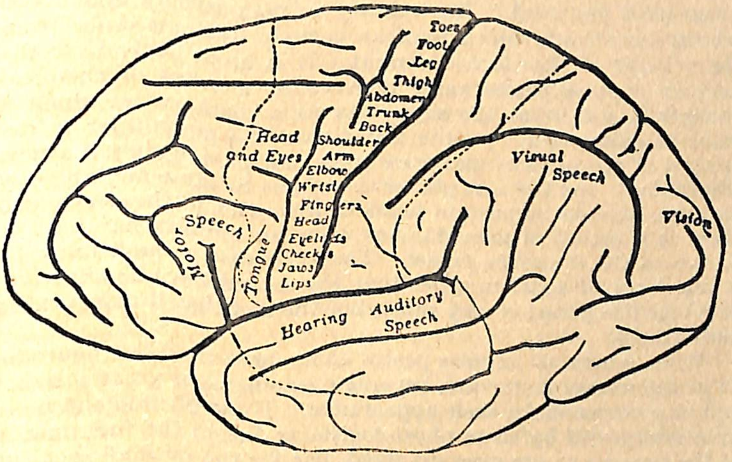


FIG. 25.—Functional areas of cortex.

located on the inferior and posterior portion of the frontal lobe, and particularly the portion of the cortex known as the hippocampal convolution. This area and the olfactory bulbs may be taken as fairly definite and certain for smell, but there is some doubt with regard to taste. No area associated with pain has yet been discovered.

As we have seen, the *association areas* are those areas of the cortex to which no definite function can be assigned. There are four important areas of this kind. The first comprises the greater part of the frontal lobe—all the area in front of the motor zone. The second is in the parietal lobe between the kinæsthetic and cutaneous area and the visual area. The third occupies the

greater part of the temporal lobe. The fourth is the insular lobe or island of Reil.

On the basis of pathological evidence it has been determined that the areas concerned in the mechanism of language are fairly circumscribed areas, two in the motor zone with one in the visual area and one in the auditory. In the study of cases of aphasia it has been found that a pathological condition in each of these areas is correlated with a particular type of language disturbance.

Nervous Process.—We are still ignorant as to the precise character of the nervous impulse. Physiologically, the only evidence we can obtain of the passage of an impulse along a nerve is the series of electrical changes produced. The measurement of the velocity of the impulse, however, precludes the idea of its being itself electrical. The velocity in man is only about 120 metres per second, which is of an entirely different order from the velocity of the electric current. It is more likely that the nervous impulse passes along a nerve by a series of chemical changes in somewhat the same way as a spark passes along a train of gunpowder. In the latter case the gunpowder is destroyed in the process, and a spark cannot pass again till a new train is laid. At the first glance this seems to cause any analogy with the nervous impulse to break down. But in the nerve also there is a period of inexcitability after an impulse has passed, known as the *refractory period.* Two successive stimuli must be a longer period apart in order that the second may be effective. It is true this period is very short, but the fact that it exists saves our analogy.

When a nervous impulse passes along more than one neurone, as in the sensori-motor arc, several phenomena of great interest and importance make their appearance. These phenomena have been interpreted by some physiologists as due to the functioning of the synapse or synapses involved, but for the psychologist the physiological interpretation is a matter of secondary importance.

(1) A feeble stimulus may be strong enough to excite a sensory neurone, judging at least by the electrical changes, but not strong enough to produce any motor change. If, however, two such stimuli be given in quick succession a motor change—for example, movement in a muscle—is produced. This is termed *summation.*

(2) The excitement of a motor system, which is produced by the stimulation of one sensory neurone, may be reinforced by the simultaneous stimulation of another sensory neurone, connected, however indirectly, with the same motor system. Even when a motor system remains unexcited owing to the fact that the stimulation of the sensory neurone is too feeble, the stimulation of another sensory neurone, though in an equally feeble way, may produce excitement in the motor system. This is termed *facilitation,* but it is evidently a particular case of summation.

(3) Facilitation, however, does not always take place under these conditions. In different parts of the body there are pairs of antagonistic muscles or muscle systems. In such cases there may be reciprocal inhibition. That is, the activity of the one muscle tends to inhibit the activity of the other. Hence the effect of a sensory stimulus may be to inhibit the activity of a motor system already active, because of the fact that it evokes the activity of an antagonistic motor system. Phenomena analogous to those of facilitation and inhibition in the sensori-motor arc are found at all levels of the nervous system.

The stimuli that excite a nervous impulse are normally received only at the terminal arborizations of the dendrites. It has been shown experimentally, however, that a nerve fibre can be excited at any point. Thermal, chemical, mechanical, or electrical stimulation may excite a nervous impulse when applied directly to a nerve fibre. The question has long been discussed whether the nervous impulses in different nerves are similar, whether the nervous impulse, for example, in a motor nerve is similar to that in a sensory nerve, that in the auditory nerve similar to that in the optic. According to the *theory of the specific energy of nerves* the character of the impulse in a nerve is specific to that nerve. The view generally accepted, however, is that, as far as the nerve fibre itself is concerned, the character of the nervous impulse is identical in all nerves.

So far, we have discussed only the cerebro-spinal nervous system, and the autonomic system has been passed with the bare mention. The fact is that it is the cerebro-spinal system that functions as the connecting group of cells in the psycho-organic system as a whole. From this point of view the autonomic system is not merely secondary and subordinate, but it really belongs, not to the connecting group of cells, but to the effectors. As such, we shall have to discuss it presently.

The Effectors

The effectors comprise the cells composing the muscles and glands. In each case two groups must be distinguished, among muscles, the striped, voluntary, or skeletal muscles, and the smooth or involuntary muscles, and among glands, the duct glands, and the ductless or endocrine glands. In addition, we must regard the autonomic nervous system as belonging here, and as associated particularly with the involuntary muscles and the glands.

The striped or voluntary muscles are of different shapes and sizes. Their structural unit is the muscle fibre or cell. In each muscle there are numbers of these cells, grouped in bundles, and generally lying parallel to the long axis of the muscle. The

muscle, as a whole, is surrounded by a sheath. The medullary sheath of motor nerves passing into the muscle disappears at this muscle sheath. The nerve then breaks up into numerous fibrils, and these terminate in the so-called "end plates." Muscles also possess receptor organs, from which sensory fibres pass, as well as endings of sympathetic or autonomic fibres.

Unstriped or involuntary muscles form the walls of the alimentary canal, the visceral organs, and the blood-vessels. The type of muscle cell in these differs markedly from that of the striped muscle. It is small and spindle-shaped. Such cells unite to form membranes. Generally speaking, the unstriped or smooth muscles have their nerve supply from the autonomic system.

The other group of the effectors consists of the glands, duct and ductless. These play a principal part in vital process, but are also active in the response of the organism to environmental stimuli. The chief duct glands in the body are those of the liver, the pancreas, the kidneys, with those that secrete saliva, gastric and digestive juices generally, and sweat. The main endocrine glands are the thyroid and parathyroid, the adrenal, the pituitary. These cells, as also the sexual glands and the pancreas, secrete an internal secretion, which is passed into the blood directly, and stimulates or inhibits activity in other parts of the organic structure—*hormones* or *autacoid substances*.

As we have seen, the autonomic nervous system is a secondary connective system belonging to the effector side of the psycho-organic system, and controlling and co-ordinating in particular the activity of the involuntary muscles and the glands. It is apparently purely motor. At least there is no definite evidence to show that it has an afferent system of its own. Fibres pass out from cell bodies in the spinal cord which end in autonomic ganglia. By means of such fibres the autonomic system is partly controlled by the cerebro-spinal, but its activity can also be aroused independently of the cerebro-spinal, in particular by autacoids from the endocrine glands.

The autonomic system comprises a chain of ganglia running parallel on each side to the spinal cord, the two chains uniting below in a single ganglion, four ganglia on each side in the head, together with ganglia scattered among the visceral organs in the thorax, abdomen, and pelvis. The nerve fibres of the autonomic system are non-medullated, and covered directly with neurilemma. As a result, they have a grey appearance as contrasted with the white fibres of the cerebro-spinal system.

APPENDIX B

SHORT METHODS OF CALCULATING CORRELATION

THE formula given for calculating correlation in the text (Introduction) is the Bravais-Pearson " Product Moments " formula. This is the standard fromula, but its employment involves somewhat lengthy arithmetical calculation, even when tables are used. Consequently, short methods of calculating correlation are more frequently employed. Of these short methods, the favourite one is probably the Spearman " Foot-Rule " formula. To use this the individuals must first be arranged in ranks in the two series—first, second, third, etc. All instances in which an individual has gained a place or places in the second series as compared with the first are noted, and the sum of the places gained ascertained. The formula indicating correlation is then :—

$$R = 1 - \frac{6\Sigma g}{N^2 - 1},$$

where Σg is the sum of gains, and N the number of cases.

The relation of this coefficient R to the Pearson coefficient r is given by the formula :—

$$r = \sin\left(\frac{\pi}{2}R\right).$$

A still simpler formula may be employed, at least provisionally and as a first approximation, to indicate the relation between two series of measurements. If we let

a equal the number of individuals above the mean in both series ;

b the number of cases below the mean in both ;

c the number of individuals above the mean in the first, but below the mean in the second ; and

d the number above the mean in the second, but below the mean in the first, then the formula :

$$\frac{ab - cd}{ab + cd}$$

will give approximately the relationship, or will, at least, indicate whether any marked degree of correlation exists. Another formula on the same basis, but giving a closer approximation, is :—

$$\omega = \frac{\sqrt{ab} - \sqrt{cd}}{\sqrt{ab} + \sqrt{cd}}.$$

where ω is what Udny Yule has called the "Colligation" or "Association" coefficient. The Pearson coefficient can be approximately obtained from it by the same formula as in the case of R, i.e. $r = \sin\left(\frac{\pi}{2}\omega\right)$.

APPENDIX C

THE EFFECTS OF DRUGS

CLOSELY connected with the effects of fatigue, at least with fatigue caused by loss of sleep, is the effect of drugs. This ought, perhaps, to have been considered in the Chapter on Work and Fatigue, but the following short note must suffice.

Any investigation into the effect of drugs and stimulants requires careful experimental technique, if the results are to be in any measure satisfactory. For instance, individuals who act as subjects are influenced by suggestion. Certain results are expected, and the phenomena which are described after partaking of the drug may be as much caused by suggestion as by the drug itself. As a matter of fact, much of the experimental work on drugs has been discredited because of the failure to eliminate the influence of this factor. To eliminate suggestion in its entirety is sometimes impracticable. But the chief method adopted is to disguise the drug by mixing it in some neutral substance—a method employed and suggested by Rivers. This disguised substance is taken regularly by the subjects; sometimes it contains the drug, at other times it is a harmless potion. The subjects, however, are unaware of the changes in the disguised mixture, and accordingly if suggestion does play an important rôle in the experiment its influence can be seen both with the harmless mixture and with the drug, and in consequence such effects can be discounted.

A second precaution adopted in the technique of drug experiments is that of having a control group. Such a group consists of subjects who receive daily, or as arranged, doses of the mixture, along with the other subjects. They are open to all the influences of the subjects proper; they are tested in precisely the same manner, and with the same tests; but on every occasion they have been given, not the drug, but a harmless mixture. Such groups are, in consequence, comparable.

A further difficulty in drug investigations is the devising of suitable tests, tests which are purely objective in character. Subjective criteria are not always reliable, and do not always

correspond with actual performance. This is well illustrated in a very interesting series of experiments carried out by McDougall and Smith.[1] A common subjective effect which was present during many of the alcohol experiments was the pleasant conviction that the experiment was being well done: "in fact, that particular view persisted long after the delusive nature of the experience was well known, and it frequently crossed the subject's mind that in this or that particular case alcohol was not having its usual effect, only to find the customary increase in the errors made when they were counted."[2] Two objective tests recommended as a result of this investigation are the "dotting machine" (devised by McDougall), which is a test of sustained voluntary attention, and the "windmill illusion." This latter is claimed to be a delicate index of the effect of any drug, the plan adopted being that of trying to hold each phase of the illusion as long as possible. With one subject, a small dose of 10 c.c. of absolute alcohol (mixed with three times its bulk of water), was sufficient within half an hour after it had been taken, to reduce the rate of alternation by nearly 50 per cent.

The general effect of alcohol is to increase the number of errors in any task, a greater number showing after an interval, say, of an hour than immediately after partaking of it. Again, alcohol to the amount of 30 c.c. taken with a meal produces slight effects either subjective or objective, but when taken from two to five hours after a meal, the effects are clearly indicated. In taking alcohol when fatigued from voluntary lack of sleep for a few consecutive nights, McDougall and Smith found that alcohol acts in a harmful manner when the fatigue effects are in evidence, but as the approach to normal takes place, the phenomena are different, a notable decrease in errors is made and the drug seems to act beneficially.

The chief drugs which have been investigated are nicotine, caffein, alcohol, strychnine, and opium.

[1] "The Effects of Alcohol and some other Drugs during Normal and Fatigued Conditions." Medical Research Council, Special Report Series, No. 56.

[2] *Ibid.*, p. 9.

APPENDIX D

GESTALT PSYCHOLOGY

THE apparent attempt of Gestalt psychologists to rewrite psychology is based upon an experimental psychology differing in many respects from what we may call the classical experimental psychology. In a text-book of experimental psychology some notice must obviously be taken of the experimental work of these psychologists, whatever may be our attitude towards the Gestalt theories. It cannot be said, however, that this experimental work is independent of the theories. If one were to attempt a criticism of Gestalt psychology it would start from this point. In their anxiety to avoid anything of the nature of an atomistic psychology, and to emphasize organization and " wholes " in our experience, there is a tendency for these psychologists to concentrate upon certain types of experience and certain types of experiment. As a result they appear too often to lose all perspective, and not infrequently to rest satisfied with experimental investigations that are highly artificial as to content, and inadequately controlled as to method.

The field in which the most important and most characteristic work of the Gestalt psychologists has been done is the field of sense perception, and what is possibly the most valuable of their original contributions to psychology as a whole is in this field. It might almost be said that Gestalt psychology, so far as it is really new and original, is characteristically an attempt to apply through the whole range of mental phenomena the chief results of the findings reached in the study of sense perception, particularly of visual sense perception.

It is of very great importance that we should be clear on this point. Organization in experience may be of different orders and dependent upon different conditions. In a living organism there is an interconnection between all the parts, so that no modification can take place in any part without all other parts being affected to a greater or less extent. We might speak of this as " vital " organization, and regard it as dependent upon a *dynamic of organism.* Then there is an organization in our sensory experience, which appears to be conditioned by forces in the sensory field itself. This we may call " field " organization, and regard as dependent upon a psycho-physical dynamic at the sensory

level. But there is also a cognitive organization and a conative organization, which other psychologists have described and discussed, and which cannot apparently be reduced to either or both of the other types. It might fairly be said that the Gestalt psychologists emphasize to an almost exclusive extent the type of organization which is conditioned by forces—tensions—in the psycho-physical field, of which the chosen model appears to be organization in the sensory field. Psychologists, like Spearman, seem to emphasize in an almost equally exclusive way cognitive organization, and an emphasis, though not exclusive, on conative organization is very characteristic of Stout's teaching. These two latter types of organization, however, the Gestalt psychologists do not appear to recognize as types differing in any way from the organization due to psycho-physical dynamic in the sensory field.

Some of the work upon which the conception of a field dynamic in sensory experience rests, has already been alluded to (Chapter VI). Here the chief phenomena of this dynamic may be illustrated by a brief description of typical experiments.

I. *Figure and Ground :* A sensory field always presents characteristics, which the Gestalt psychologists, following Rubin, usually describe as " figure and ground." This means that part of the sensory field stands out as a segregated whole upon a background formed by the remainder of the field. The part of the field which becomes " figure " at any time is determined by various conditions which may be experimentally investigated. For example, suppose we have a number of dots (or lines or shapes) scattered more or less irregularly over a presented visual field. The conditions under which they will fall into segregated groups can be readily determined. A segregated group will then stand out as a " figure " on the ground of the rest of the field. The main conditions which favour the formation of segregated groups appear to be :

1. close proximity to one another of a number of dots,
2. some common characteristic of some of the dots, differentiating them from the others, such as shape, size, or colour,
3. the formation by some of the dots of a simple, regular, or closed figure.

II. *Prägnanz and Closure :* Simple experiments of the same kind will also serve to bring out the influence of what the Gestalt psychologists call " prägnanz " and " closure." By " prägnanz " is meant the tendency for the organization to be as " good " as possible in the existing conditions, that is, as regular, simple,

stable, etc., as possible. This tendency, as it were, expresses the interaction of the forces or tensions in the sensory field, so as to bring about a state of relative equilibrium. " Closure " is at one and the same time a condition and a result of this tendency. Closed areas have a stability of organization which gives them an ability to resist any modifying or disrupting forces. Not only so, but closed figures may be perceived when there are really gaps in the objective patterns, where the closure of these gaps produces a stable figure, and this again as a result merely of sensory dynamic.

Another way of regarding the phenomena is to consider the gaps (and the same is true of irregularities and the like) as setting up tensions in the psycho-physical field, which only disappear with the closing of the gap. The phenomena are encountered again in learning and in thinking, according to the Gestalt reading of the situation.

Both " prägnanz " and " closure " exemplify, therefore, the distribution of tensions in the sensory field. In illustration certain phenomena of simultaneous colour contrast may be taken. Let us quote from Koffka :[1]

" On a ground half red, half green, lies a grey ring. Looked at naïvely, it will appear more or less homogeneously grey. Now divide the circular ring into two semicircular ones by laying a narrow strip of paper or a needle on top of the boundary between the red and the green fields. At once the semicircular ring on the red field will look distinctly greenish, that on the green field distinctly reddish. We may express the result of this experiment thus : a unified figure will look uniform under conditions where two segregated figures produced by the same stimuli will look different from each other."

These, however, are not all the facts, though the additional facts do not appear to affect the main contention. The breadth of the circle has very marked influence on the experience. If the circle is, say, half an inch in breadth, it may be seen, as Koffka states, as a practically uniform grey, whereas if it is only an eighth of an inch in breadth, it is by no means uniform in appearance, even before it is divided into semicircles. The phenomena, of course, have been long known, and have been investigated even more systematically and more carefully by the classical experimental psychology than by the Gestalt psychology. Analogous phenomena appear when the circle (or a cross) is observed directly, and under a sheet of tissue paper, the effect of which is to make the contours of the circle less definite.

[1] *Principles of Gestalt Psychology*, p. 134.

III. *The Constancies:* The phenomena grouped together under this head are probably the most interesting of all the perception phenomena discussed by Gestalt psychologists. There may be some question, however, whether they belong with the other sensory phenomena. They are described as phenomena of the "framework" within which organization takes place, and by which the organization itself is influenced. The influence of the framework is perhaps best illustrated by the experiment of projecting after-images on to surfaces at different distances, in different directions, and inclined at different angles to the vertical; the size or shape of the after-image will be correspondingly altered.

The so-called "constancies" represent what might be described as the converse of this. Our experience of shape, size, brightness or colour is determined in part by the retinal impression, but in part also by the "real" object. If, for example, the "real" object is a circle, lying in a plane inclined to the line of vision, the retinal image is an ellipse, but our experience is of a circle, and if we attempt to equate to the circle as seen, an ellipse in a plane normal to the line of vision, that ellipse will approach more closely the circular form than does the ellipse actually impressed on the retina.

Investigators of these phenomena, like Thouless, for example, speak in such cases of "phenomenal regression towards the real object." Phenomenal regression is also exhibited in the case of size. The size of a near square equated to a distant square is usually much nearer the "real" size of the distant square than it would be if determined by the relative sizes of the retinal images.

Even more striking are the phenomena in the case of brightness and colour. The chief work in this field has been done by Katz and Gelb. If a white disc is placed in low illumination—at a distance from the source of light, or in shadow—it still looks *white*, although it may be described as in low illumination or in shadow. If now an attempt is made to equate to it a rotating disc with white and black sectors, placed in full light, it will be found that an exact match cannot be obtained, but only what looks at best an approximate match. An exact match may be obtained by using a "reduction screen." This is a sheet of grey cardboard interposed between the subject and the discs, with two apertures so placed that one disc is seen through one, the other through the other. When the approximate match obtained directly is looked at through the reduction screen it appears much too light, whereas if the match obtained with the reduction screen is regarded without the screen, it appears much too dark.

These phenomena lead Katz to an important distinction between *film* colours and *body* or *surface* colours. It seems as if the laws of physical optics apply to the former and not to the latter.

Similar phenomena appear with colours. If a white disc is illumined with filtered red light and a red disc is simultaneously illumined with white light, it is impossible to get anything but a very poor approximation to a match by any change of illumination or addition of white to the red disc. The white disc always looks *white in red illumination*. On the other hand, with a reduction screen a match is easily obtained.

Gelb has described a beautiful experiment in which black is made, as it were, to become white. If in a dark room a black disc is brightly illumined, it will appear white and the rest of the visual field black. If, however, the experimenter now introduces a small piece of white paper into the cone of illumination and close to the black disc, the latter at once looks black.

IV. *Perceived Motion :* The work by Wertheimer on perceived movement, already referred to in Chapter VI, represents the beginning of the systematic development of Gestalt psychology. Wertheimer's experiments were experiments on stroboscopic movement, and are at once the best illustration of, and the best evidence for, that sensory dynamic upon which the Gestalt psychologists lay such stress.

To sum up the situation. No one can be in any doubt regarding the conclusiveness of the evidence adduced by the Gestalt psychologists in favour of the view that there is a sensory dynamic upon which the organization of our sensory experience depends, at least in part. Nor can one be in any doubt as to the very real value of the contribution made to our science by the Gestalt psychologists in this connection. That our whole experience, however, at all levels, can be adequately described on a similar basis is more than doubtful. In accounting for depth perception the Gestalt psychologists specify the usually accepted depth factors, and proceed as before to " explain " on the basis of sensory dynamic. At this point their psychology begins to seem less adequate. When learning, thinking, emotion, and volition are crushed into the same mould, the ordinary psychologist begins to rub his eyes, and to wonder if he has all along been under a delusion in thinking that cognition and judgment involved an organization of a different order altogether, interest and purpose another kind of organization still. The attitude, too, of Gestalt psychologists to the problem of " meaning " suggests an oversimplification of the phenomena, and at times even a misunderstanding of the situation.

APPENDIX E

BELOW is given a list of books for further reading in connection with each chapter.

General Books on Experimental Psychology

Myers. Textbook of Experimental Psychology. Parts 1 and 2.
Titchener. Experimental Psychology, Qualitative. Parts 1 and 2. Quantitative. Parts 1 and 2.
Schulze. Experimental Psychology and Education. Trans. by Pintner.
Seashore. Elementary Experiments in Psychology.
Sanford. Experimental Psychology.
Witmer. Analytical Psychology.
Stratton. Experimental Psychology.
Scripture. The New Psychology.
Scripture. Thinking, Feeling, Doing.
Woodworth. Contemporary Schools of Psychology.

Introduction

Brown and Thomson. Mental Measurements.
Dawson. Computation of Statistics.
Scripture. The New Psychology.
Titchener. Experimental Psychology.
Udny Yule. Introduction to Statistics.

Chapter I

Collins. Colour Blindness.
Edridge Green. Hunterian Lectures on Colour Vision and Colour-Blindness.
Greenwood. Physiology of the Special Senses.
Ladd-Franklin. Colour and Colour Theories.
Parsons. Introduction to Colour Vision.
Rivers. Article on Vision in Schafer's Textbook of Physiology.

Chapter II

Helmholtz. Sensations of Tone.
Miller. The Science of Musical Sounds.
Watt. The Psychology of Sound.
Watt. The Foundations of Music.

Chapter III

Greenwood. Physiology of the Special Senses.
Head. Studies in Neurology.
Scripture. Thinking, Feeling, Doing.

Chapter IV

Gamble. Review of Henning. American Journal of Psychology, 1921, Vol. XXXII, pp. 290-295.
Greenwood. Physiology of the Special Senses.
Hollingworth and Poffenberger. The Sense of Taste.
Scripture. Thinking, Feeling, Doing.

Chapter V

Greenwood. Physiology of the Special Senses.
Sherrington. The Integrative Action of the Central Nervous System.
Woodworth. Le Mouvement.

Chapter VI

Galton. Enquiries into Human Faculty.
Koffka. Principles of Gestalt Psychology.
Köhler. Gestalt Psychology.
Pear. Remembering and Forgetting (Coloured Thinking).
Pierce. Studies in Space Perception.
Scripture. Thinking, Feeling, Doing.
Stout. Manual of Psychology.
Wolters. The Evidence of our Senses.

Chapter VII

James. Principles of Psychology.
Pillsbury. Attention.
Ribot. Psychology of Attention.
Titchener. Lectures on the Elementary Psychology of Feeling and Attention.

Chapter VIII

McDougall. Physiological Psychology.
Scripture. The New Psychology.
Titchener. Experimental Psychology.
Watson. Psychology from the Standpoint of a Behaviourist.

Chapter IX

Drever. Psychology of Industry.
Mosso. Fatigue.
Muscio. Lectures on Industrial Psychology.
Myers. Mind and Work.
Myers (edited by). Industrial Psychology.
Poffenberger. Applied Psychology.
Psychological Effects of Drugs, Psy. Bulletin, 1922.
Viteles. Industrial Psychology.

Chapter X

Baudouin. Suggestion and Auto-suggestion.
Binet. La Suggestibilité.
Jastrow. Fact and Fable in Psychology.
Sidis. The Psychology of Suggestion.
Whipple. Manual of Mental and Physical Tests.

Chapter XI

Cannon. The Bodily Effects of Pain, Hunger, Fear, and Rage.
Darwin. The Expression of the Emotions in Man and Animals.
McDougall. Social Psychology.
Watson. Psychology from the Standpoint of a Behaviourist.
Whately Smith. The Measurement of Emotion.
Wohlgemuth. Pleasure-Unpleasure, British Journal of Psychology, Monograph Supplement VI.

Chapter XII

Betts. The Distribution and Functions of Mental Imagery.
Galton. Enquiries into Human Faculty.
James. Principles of Psychology.
Jung. Studies in Word Association.
Rusk. Experiments on Mental Association in Children, British Journal of Psychology, Vol. III, p. 349.

Chapter XIII

Bartlett. Remembering.
Colvin. The Learning Process.
Köhler. The Mentality of Apes.
Mace. The Psychology of Study.
Meumann. Psychology of Learning.
Pyle. A Laboratory Guide in the Psychology of Learning.
Thorndike. Educational Psychology.

Chapter XIV

Aveling. Consciousness of the Universal.
Binet. L'Etude Experimentelle de l'Intelligence.
Moore. The Process of Abstraction.
Ribot. The Evolution of General Ideas.
Spearman. The Nature of Intelligence and the Principles of Cognition
Titchener. Experimental Psychology of the Thought Process.
Whipple. Manual of Mental and Physical Tests.

Chapter XV

Dodge. Psychological Review Monograph Supplement VIII.
Huey. Psychology and Pedagogy of Reading.
Judd. Introduction to Genetic Psychology.
Stout. Analytic Psychology.
Stout. Manual of Psychology.
Watson. Psychology from the Standpoint of a Behaviourist.

Chapter XVI

Ballard. Mental Tests.
Ballard. Group Tests of Intelligence.
Binet and Simon. The Development of Intelligence in Children.
Burt. Mental and Scholastic Tests.
Drever and Collins. Performance Tests of Intelligence.
June-Downey. The Will-Temperament and its Testing.
Knight. Intelligence and Intelligence Tests.
Macrae. Talents and Temperaments.
Pintner. Intelligence Testing.
Pintner and Paterson. A Scale of Performance Tests.
Poffenberger. Applied Psychology.
Yerkes-Bridges. A Point Scale for Measuring Mental Ability.
Yoakum and Yerkes. Mental Tests in the American Army.

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